Marine Science Development in Tanzania and Eastern Africa

Edited by Matthew D. Richmond and Julius Francis

Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania
28 June–1 July 1999
Zanzibar, Tanzania
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Preface

The Conference on 'Advances in Marine Sciences in Tanzania', on which this Proceedings is based, was organised in Zanzibar, Tanzania from 28 June–1 July 1999. It was organised by the Institute of Marine Sciences of the University of Dar es Salaam with support from Sida-SAREC, CIDA through the Memorial University of Newfoundland–University of Dar es Salaam (UDSM) Linkage Programme, and USAID through the Tanzania Coastal Management Partnership (TCMP). The Conference was organised as part of the celebrations to commemorate the twentieth anniversary of the Institute of Marine Sciences. Similarly, the Conference was used to mark 10 years since the initiation of Sida-SAREC East African Regional Marine Science Programme and the Memorial–UDSM Linkage Programme. These two programmes have been instrumental in building both technical and human capacity at the Institute and in the collaborating institutions.

The main objectives of the Conference were threefold:

• To provide a forum for discussion and exchange of information on marine sciences in Tanzania and the western Indian Ocean (WIO) region in general;
• to brainstorm on the research agenda for the future for Tanzania and the WIO region; and
• to raise awareness on the contribution being made to our understanding of the coastal and marine environment and the development of marine resources.

Over 70 papers and posters were presented during the three-day Conference, which was attended by more than 100 participants from eastern and southern Africa, Europe, USA and Canada. Regional and international organisations were also represented, including: the Western Indian Ocean Marine Science Association (WIOMSA), the Secretariat for Eastern Africa Coastal Area Management (SEACAM), United Nations Environment Programme (UNEP), Intergovernmental Oceanographic Commission (IOC), Sida-SAREC and CIDA.

More importantly, one full day was devoted to discussions on 'the way forward'. This special session, titled 'Marine research for development: Challenges for the new millennium', was based on group discussions. These groups identified and proposed priority research areas, research approaches, mechanisms for implementation, and resource mobilisation. The priority areas for research proposed at the Conference formed an integral part of the new regional programme, Marine Science for Management (MASMA), funded by Sida/ SAREC and implemented by WIOMSA.

The 45 papers included in this Proceedings are derived from the Conference and they focus on research that has been undertaken in the Western Indian Ocean region. They present results of original research as well as reviews on a number of subjects. The papers are grouped into five major sections reflecting the scope of scientific disciplines now present in the region. Following the Introductory Statements are the other sections, namely: Physical and Geological Processes, Water Quality and Nutrient Dynamics, Ecology of Coastal Ecosystems, and Socioeconomic Aspects and Management Options. Each section comprises between 8 and 12 papers that cover research from a broad range of themes.
and a wide variety of localities within the region. A summary of the contents of each section is provided below.

INTRODUCTORY STATEMENTS
The history of the Institute of Marine Sciences, from its inception 20 years ago to the present, is described. The important role of the University of Dar es Salaam, the donor community, and the Government of Zanzibar in supporting the development of a marine research capability for Tanzania are described. This research capacity, built with the assistance of Sida-SAREC and other organisations, is beginning to generate data and information resulting from the research projects undertaken in the last 10 years. This research now makes a positive contribution to an improved understanding of the marine processes vital to the well-being of coastal populations of Tanzania and the region.

PHYSICAL AND GEOLOGICAL PROCESSES
Movement and sources of organic sediments in shallow inshore ecosystems and the processes that govern erosion of local beaches are examined. The frequency of coastal winds and the mobility of mid-ocean ridges over the past 75 million years are also investigated.

WATER QUALITY AND NUTRIENT DYNAMICS
The findings of research investigating the importance of seawater quality and nutrient levels to marine processes such as calcification in algae, and the accumulation of toxins in algae and coral reefs are presented, as are data on the role of mangroves in nutrient cycling and coastal productivity. The impact of coastal pollution and the alteration of coastal habitats for seaweed farming are investigated, and the potential for use of algae to reduce organic pollution in fish tanks is considered.

ECOLOGY OF COASTAL ECOSYSTEMS
Diverse studies of the biodiversity of habitats, taxonomy of species and ecological processes, such as the 1998 coral bleaching event, are presented. The reproduction and growth of reef squid, swimming crabs and the presence of harmful microalgae in coastal waters are investigated.

SOCIOECONOMIC ASPECTS AND MANAGEMENT OPTIONS
The socioeconomic aspects of human existence in the coastal zone and the importance of communication and awareness among stakeholders, are considered in the papers in this section. Regional examples of the involvement of the local communities in resource management and the development of alternative uses of coastal resources are described.

This Proceedings represent a reflection of the increase in scientific interest and capacity in the region that has led to an increase in research projects funded by different organisations, as well as the number of projects on the ground. We hope that it will serve a useful purpose for a wide range of stakeholders, including academicians, students, decision makers and others.
Acknowledgements

The Conference on ‘Advances in Marine Sciences in Tanzania’ was organised by the Institute of Marine Sciences (IMS), University of Dar es Salaam which provided both technical and logistical support during the Conference preparation and execution. Their able assistance, support and warm hospitality created a congenial Conference atmosphere. The organisers are indeed very grateful to the members of the Scientific Committee (Drs M. Mtolera, N. Jiddawi, S. Mohammed) and the Public Awareness Committee (Drs D. Masalu, A. Dubi and M. Kyewalyanga and Mr E. Turuka) for their untiring efforts and valuable advice throughout the Conference preparation and execution. We express our sincere appreciation to the other remaining Institute’s staff who were also involved directly and indirectly in the Conference preparation and execution.

We thank all the participants who worked so hard and whose active participation and co-operation ensured a successful Conference. We deeply appreciate and acknowledge their contribution.

This Proceedings embodies the hard work of many authors and production individuals. The authors of the papers included here have done so in their personal capacity and do not in any way represent the views of their institutions. All of them deserve our special thanks and appreciation for sharing their skills and knowledge. The unheralded efforts of the 30-plus peer reviewers is also gratefully acknowledged. Ms Daisy Ouya was responsible for all aspects of production, including copyediting, typesetting, graphics and proofreading, as well as a variety of technical matters essential to the publication of the book. Her input is highly acknowledged. The publication of this Proceedings would not have been realised without the generous financial support of WIOOMSA.

The editors wish to thank all the contributing authors for their patience and cooperation during the preparation of this Proceedings. The editors also take full responsibility, and apologise in advance, for any errors or omissions found in the final papers.
DEDICATION

Adelaida K. Semesi
1951–2001

While in the process of finalising this Proceedings, Professor Adelaida K. Semesi, the Director of the Institute of Marine Sciences, University of Dar es Salaam, passed away on 6 February 2001. The news of her demise overwhelmed us with grief.

Adelaida attended the Conference on 'Advances in Marine Sciences in Tanzania' and chaired its first session, at which all the keynote presentations were delivered. She assumed the task as always, with great dedication and enthusiasm, as was typical of her. Hence, she made an important contribution to the success of the conference.

Adelaida was an outstanding scientist who, besides teaching, conducted research and consultancy extensively. Her research on seaweed, seagrasses, mangroves and microbiology has been a source of learning and inspiration for a generation of young marine scientists in the WIO region. Adelaida was not only a theorist; she also worked on field projects along the eastern African coast and gained a great deal of practical experience.

Throughout her academic career, Adelaida undertook her work and life with warmth, enthusiasm, support and understanding. All of us who were fortunate to work with her have benefited immensely, and will continue to derive rewarding experience from her various undertakings. She will be missed by the scientific community and all those whose lives she touched in one way or other.

In recognition of her untiring service and contribution to marine science development in the WIO region, this proceedings is dedicated to the memory of Professor Adelaida K. Semesi.
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Welcome address

Julius Francis

Director, Institute of Marine Sciences
University of Dar es Salaam, P.O. Box 668, Zanzibar, Tanzania

Honorable Chief Minister, Dr M. Bilal,
Your Excellency, Ambassador of Sweden, Dr Sten Rylander,
Honorable Minister of Agriculture, Livestock and
Natural Resources, Brigadier General A. Mwakanjuki,
The Acting Chief Academic Officer, Prof. Kanyanwi,
Distinguished guests,
Ladies and gentlemen,
Madam Chairperson,

May I on behalf of myself and the Institute of Marine Sciences, welcome you all to this Conference.

First and foremost, I would like to thank the Honorable Chief Minister, for accepting our invitation to officiate at the opening ceremony of this Conference, despite the short notice. We also feel very honoured to have the Ambassador of Sweden with us this morning.

It is with great pleasure that I see our dream of organising a Conference on Advances in Marine Sciences in Tanzania, to commemorate the 20th Anniversary of the Institute of Marine Sciences, being fulfilled this morning. The organisation of the Conference has taken a great deal of will and determination, but above all, good cooperation from all of you here today. The swift and positive response from all of you went a long way to ensure its materialisation.

On this occasion, we are also marking yet another milestone. This year is ten years since the initiation of two key programmes at the Institute, these are the Sida-SAREC East African Regional Marine Science Programme and the Memorial University of Newfoundland–University of Dar es Salaam Linkage Programme funded by the Canadian International Development Agency (CIDA). These two programmes have played a major role in making the Institute what it is today.

The Institute was established on 1 July, 1979, as a successor to the East African Marine Fisheries Research Organisation (EAMFRO), following the collapse of the East African Community. The new Institute was then charged with the responsibility of providing knowledge through research in all aspects of marine sciences, providing postgraduate training as well as providing consultancy and advisory services to government, non-governmental organisations, the general public and the private sector.
Development of the Institute has taken place in five main phases. Phase one, covering the period (1979–1989), concentrated on staff recruitment. The second phase, which overlapped with the first phase (1984–1995), concentrated on staff training. The third, lasting from 1994 to 1997, was focused on improvement of infrastructure, while the fourth which could be taken to begin from 1995, is steeped more in scientific research in accordance with the IMS mission. Concurrently, we have began implementing the fifth phase which is on initiation of demonstration activities such as fish farming.

In its twenty years of existence, the contribution of the Institute has been and continues to be manyfold: research activities have mainly been oriented towards understanding the coastal and marine environment, as well as providing relevant information applicable to management, utilisation and conservation of coastal and marine resources. More specifically the Institute has made significant contributions to national, regional and international initiatives as highlighted by the following examples:

- The Institute was involved in the development of the following policies: the Environmental Legislation for Zanzibar and the Marine Parks and Reserves Act of 1994. Currently the Institute is involved in the process leading to the drafting of the following policies: the Agriculture and Natural Resources Policy for Zanzibar and the National Policy for Integrated Coastal Management.

- The Institute played a key role in the establishment of the Marine Island Marine Park and is currently working towards establishment of the second marine park at the Mnazi Bay in Mtwara.

- The Institute is attaching special importance to regional activities/initiatives. With the support of the United Nations Environment Programme (UNEP) in particular, IMS has or is co-ordinating a number of projects of the Eastern Africa Action Plan. The Institute has also been involved in other initiatives such as the Pan-African Conference on Sustainable Integrated Coastal Management (PACSICOM) and the Arusha and Seychelles Ministerial Policy Conferences on Integrated Coastal Management.

Coming back to this Conference, I wish to inform that this Conference has been organised not only to commemorate the 20th Anniversary of the Institute, but also equally important to serve a number of important and practical functions:

- to provide a platform for marine scientists from Tanzania, the region and abroad to present the fruits of their works, and to have them critically examined by their peers;
- to brainstorm on the research agenda for the future, for Tanzania and the Western Indian Ocean Region;
- to act as a ‘shop window’ to raise awareness to non-marine scientists, on the contribution being made to our understanding of the marine environment and the development of marine resources, and lastly,
- to provide an opportunity for participants to discuss their work both informally and formally and hopefully make new contacts.
The Book of Abstracts provides an overview of the scope of about 60 papers that will be presented in this Conference. Almost all major disciplines are represented. It is my hope that at the end of this Conference, we would not only have grasped the complexities and importance of marine science but also appreciated the need for inter-institutional cooperation at both national and regional levels. This will ensure long-term sustainable management of the coastal areas.

The first day will be devoted to keynote presentations by Sida and CIDA as well as presentations on critical issues of regional importance. On Tuesday and Thursday, two parallel scientific sessions will be held. The whole of Wednesday is dedicated to discussions on the way forward.

As we enter a new millennium, the Institute, as part of institutions of higher learning, will continue to search for knowledge and understanding on the coastal and marine environment, as well as contribute to national and regional development through academic partnerships, development and implementation of joint research projects and by promoting students and staff exchanges. The Institute aims at projecting itself as a regional centre of excellence in marine-related research, based on its modest achievements and through strategic partnership at home and abroad.

Sir Isaac Newton, who most of us have heard of, said many years ago:

To me, we have been children, playing on the shore
Picking up pretty pebbles from the beach...
While there beside us lay an ocean
Wide with undiscovered truth

It is my sincere hope that at the end of these four days of intense deliberations, we will realise that in our own small way we have made significant contribution towards uncovering the truth of the ocean.

We are twenty years old, to some we have been around long enough, but to others we are still a young institute. The Institute would not have reached the stage it is at today if it was not for a number of organisations. Madam Chairperson with your permission, may I on behalf of myself and the Institute, extend our sincere appreciation to the following:

Firstly, the Union Government and the Revolutionary Government of Zanzibar—both have played a key role in ensuring that the Institute sails through in what in some cases appears to be turbulent waters. To both of them we say thank you and it is our sincere hope that the Institute will continue to enjoy the support and goodwill from the two governments.

Secondly, the University of Dar es Salaam. The support that has been provided by the different University administrations has helped the Institute to slowly but steadily put its foot on the ground and start walking like the other Institutes and Faculties of the University. Your constructive criticism and guidance has been instrumental in the improved performance of the Institute in many fronts.
Thirdly, all our national, regional and international partners, without your support, little would have been achieved. These include institutions from Zanzibar, Tanzania Mainland, Kenya, Sweden, Belgium, Italy, the Netherlands, USA, Canada, UK, just to mention a few. Let us continue to collaborate for the benefit of our people and the environment they depend on.

Fourthly, we who are still at the Institute feel obliged to extend our sincere appreciation to all our previous Directors (Prof. A. Msangi, Prof. Bwathondi, Prof. A. Nikundiwe and Dr M. Ngoile) for the good work they did. They laid a solid foundation for the Institute, which has made the Institute what it is today. All of them have continuously made themselves available to assist the Institute whenever a need arises. We also wish to thank all IMS staff for their dedication to the Institute mission.

Lastly, to all the donors in particular Sida-SAREC and CIDA. Also to UNEP, IOC of UNESCO and to those that I have not mentioned. Your support and assistance has been instrumental in building both technical and human capacities in the Institute and in the collaborating institutions.

Before I take my seat, please permit me to express our deep gratitude to all who have made this Conference possible, without their support this Conference would not have been organised on such a scale. Sida-SAREC has provided significant support for this Conference and we are very grateful to them. The support provided by the CIDA, USAID and the University of Dar es Salaam is also highly appreciated.

With your help, 'Inshaallah' the Institute will be here many years to come, conducting research as per its mission.

Thank you for your attention.
Statement by H.E. Ambassador of Sweden

Sten Rylander
Embassy of Sweden, Dar es Salaam

Honourable Guest of Honour, Chief Minister Bilal,
Prof. M. Luhanga, Vice Chancellor of UDSM,
Dr M. Ngoile, Director General of NEMC,
Dr J. Francis, Director of the Institute of Marine Sciences,
Dear Colleagues and Friends,

It is a great pleasure indeed to be with you this morning at the opening ceremony of this important Conference on Advances in Marine Sciences in Tanzania. To be frank with you it was not so difficult to convince me to come since I love Zanzibar very much and since I have closely followed the political processes which have been going on here in recent times.

Let me at the outset warmly congratulate Zanzibar—the Government, all political stakeholders and all Zanzibaris, as well as the Mainland, for the agreement which was signed on 9 June—after a long, difficult and protracted process—and which we all hope will lead to normalised political relations between the ruling party and the opposition in Zanzibar. It was a great achievement indeed and all of us, your partners in the international community, have welcomed and applauded the courageous steps that were finally taken to secure a positive outcome. The agreement will no doubt make your task easier, Honourable Chief Minister: If smoothly implemented in good faith—and if other positive action is taken to try to solve one or two other related problems—it will open up the door for re-engagement and full cooperation on the part of the international donor community. I for one hope that we shall be there as soon as possible, and we are now taking the necessary preparatory steps to re-engage in some of the things we used to do in the past, particularly in the field of education.

Relations and cooperation between Sweden and Tanzania have always been and continue to be excellent. We are now preparing for a formal visit to Sweden by H. E. President Benjamin Mkapa—with a Minister from Zanzibar also being part of the delegation—at the end of August/early September. We will then try to take our cooperation to new challenging heights, primarily by further broadening it to trade and investment areas. But research will also come into the picture, since Uppsala University will be part of the programme.

Mr Chairman, education and research have always been strong components in our on-going cooperation with Tanzania. This tilt is something which I am personally very
proud of. These are very crucial areas indeed in the fight against poverty, underdevelopment and aid dependency. What can be more important for a nation than to have educated people and enough research capacity in order to be able to cope with the rapid changes in today’s globalised world? There is ample proof that those countries which prioritise education and research also have the highest returns in terms of development and economic growth.

Some four months ago I participated in a Sida-sponsored regional conference in Arusha for Eastern and Southern Africa about the need to strengthen the research capacity in basic sciences, such as mathematics, biology, chemistry and physics. What we talk about here is nothing less than science for survival. Without enough capacity in these basic fields there will be no applied research, and—what is worse—there will be no positive long-term development. A society which downplays these basic needs will have no chance to catch up or keep pace with developments in the world of today or tomorrow.

Of course Tanzania started from a low level and there is so much that still needs to be done in the fields of education and research. But the positive side of this is that we should all be inspired and highly motivated to improve the current situation. When you lag behind there should be no room for cynicism or complacency; you should try to mobilise the extra strength and energy which is always there and which enable you make headway and to catch up.

Mr Chairman, when I see and follow what is going on within the framework of our on-going research cooperation—whether it is in the more general field of basic research and sciences at the University of Dar es Salaam or in applied research, e.g. through the Institute of Marine Sciences—I get encouraged and inspired. I see dynamic action, strong commitment and high ambitions. I see research as a model for the new partnership-based approach to development cooperation. There are few neo-colonial hangovers—at least where we are involved, never having been a colonial power ourselves; and few old-fashioned donor/recipient-oriented attitudes, where donors ‘talk down from above’ to the recipients. What you see instead is committed engagement in substantive issues, a mutuality of interests and true exchanges in both directions.

Mr Chairman, Sweden and the Swedish Embassy in Dar es Salaam will continue to give strong support to research cooperation in Tanzania, and this will be done along two different lines: (1) support to capacity-building in basic research and basic sciences, primarily through the University of Dar es Salaam where Sida/SAREC is a key partner; and (2) support to special programmes in applied research with strong links to practical realities.

We are proud of having been for quite a long time a strong and reliable partner to the Institute of Marine Sciences. This relationship will of course continue and be even further strengthened as we move ahead. Through our continued support we hope to be able to build with all of you—a national and regional research capacity to help solve acute management issues in the coastal areas; and to help promote interactions between
decision-makers and the research community to find innovative and environmentally sustainable solutions to issues such as declining fish catches, beach erosion and the degradation of coral reefs.

Mr Chairman, before concluding I would like to make a reference to another challenging area where quite ambitious and long-term plans are now being developed for a close cooperation between Sweden and Tanzania, as well as the other members of the new East African Community: sustainable development around the Lake Victoria Basin, where links are drawn to similar cooperation efforts around the Baltic Sea in our region. Dr Ngoile was part of a high-level East African delegation which recently visited Sweden and the Baltic region.

Research will become one central area in this emerging cooperation. And the Institute of Marine Sciences certainly has a role to play also when it comes to Lake Victoria.

I thank you, Mr Chairman.
Address by Vice Chancellor, University of Dar es Salaam

M.L. Luhanga

University of Dar es Salaam, P.O. Box 668, Dar es Salaam, Tanzania

Honourable the Chief Minister, Dr M. Bilal,
Your Excellency, Ambassador of Sweden, Dr Sten Rylander,
Honorable Minister for Agriculture, Livestock and Natural Resources,
Brigadier General A. Mwakanjuki,
Distinguished guests,
Ladies and gentlemen,

It is a great pleasure for me personally and the University, that the Institute of Marine Sciences is twenty years old now. As parents do when their child is twenty years old, we feel that he/she has reached maturity and can make decisions about his/her well-being more independently. I hope the Institute is approaching that stage.

Honourable Chief Minister, we do understand that currently you have to deal with a number of pressing matters of national importance. Nevertheless, you have found our Conference worth the time. Your acceptance to be with us today demonstrates your own keen interest and importance you attach to the issues related to the development of science and technology, in this instance the development of marine sciences.

Honourable Chief Minister, on behalf of myself, the University, the Conference participants and on behalf of all whom have been involved in the organisation of this Conference, it is my pleasant duty to welcome you as our guest of honour. I thank you most sincerely for the honour of your presence. I wish to assure you that your statement to this Conference will be the guiding beacon of our deliberations.

Honourable Chief Minister, let me give a brief background on how the Institute came into being. In 1974, the Department of Zoology and Marine Biology of the University of Dar es Salaam organised an International Conference on Marine Resource Development in Eastern Africa, with the view to assess the need and potential for marine resources development in eastern Africa. The Conference recommended, among other things, that the University of Dar es Salaam establish a multidisciplinary, broad-based Centre for Marine Resources Studies. Consequently, the University of Dar es Salaam recommended to the Government of Tanzania, the establishment of an Institute of Marine Resource Development in Dar es Salaam. The planning phase for the physical facilities of the Institute coincided with two events: the collapse of the East African Community in 1977 and the Zanzibar Government expression of a wish that in the event of
the University of Dar es Salaam deciding to establish such an Institute, it should consider locating it in Zanzibar.

At the time of the establishment of the Institute in 1979, the University had two off-campus faculties: the Faculty of Agricultural Sciences in Morogoro and the Faculty of Medical Sciences at Muhimbili. Subsequently, these have been transformed into the Sokoine University of Agriculture and the Muhimbili University College of Health Sciences respectively. The running of the Institute of Marine Sciences and the then Faculties of Agricultural and Medical Sciences has provided the University with valuable lessons that might prove to be very useful as it embarks in its expansion plans.

Honourable Chief Minister, the University of Dar es Salaam has embarked on an Institutional Transformation Programme to make the University adequately fulfil its mission and goals as well as meeting the challenges and expectations as we approach the 21st century. For this purpose the University is currently implementing the University Level Five Year Rolling Strategic Plan 1997–2002. The Plan defines major policies and overall goals and sets broad objectives. Through the implementation of this Plan, the role of the University has been reviewed and re-defined to meet the needs of the University, the general public, the private sector, and the Government in the 21st century. Parallel efforts are therefore being made at the levels of institutes and faculties. The strategic plan defines the objectives and strategies, the execution of which are focused five years ahead in rolling operational plans. The Institute of Marine Sciences (IMS) has also developed its own Plan.

In this regard, it is my sincere hope that the Institute will use this occasion to:

- Critically review its research agenda and re-define its priorities in line with national development needs.
- Discuss on how best the results of research activities will be integrated/contribute into teaching.
- Discuss strategies to develop academic partnerships with both North and South institutions.
- Propose strategies aimed at securing more funding from different sources including the private sector to support research activities.

Honourable Chief Minister, through this Conference we are also commemorating ten years since the Sida-SAREC East African Regional Marine Science Programme and the Memorial University of Newfoundland Linkage Programme were established. For that, I thank the governments of Sweden and Canada for supporting these initiatives. The University and the Institute in particular, through these collaborations, have acquired some useful lessons that will contribute towards improving the modalities of collaboration between institutions in the South and North.

Honourable Chief Minister, I would like to acknowledge the efforts of all those who worked tirelessly in the organisation of this Conference. I would also like to record our appreciation to the Swedish Government, which has played a key role in providing
financial support through Sida-SAREC. The support from the Canadian International Development Agency and USAID is also highly appreciated.

In ending, let me say that, it is hard to succeed at the beginning, or even at all, but with persistence one can get very far and that is the story of IMS, which has not given up despite the many difficulties that they have encountered in twenty years of their existence. On behalf of myself and the University, I wish the Institute a HAPPY 20th ANNIVERSARY!

May I now welcome Honourable Chief Minister to open the Conference and I thank you for your attention.
Address by Guest of Honour, H.E. the Chief Minister of the Revolutionary Government of Zanzibar

Mohamed Gharib Bilal

Mr Chairman, let me first extend my sincere thanks to the organisers of this conference, for inviting me to officiate at this opening ceremony of the Conference on Advances in Marine Sciences in Tanzania. I would like to warmly acknowledge the presence of all colleagues and friends from the University and all of you distinguished participants, some of whom have come a long way to be with us today. On behalf of the Government, the people of Zanzibar and on my own behalf, I wish to welcome you all to Zanzibar. We urge you to make the most of our hospitality and to have an enjoyable and pleasant stay in our country.

The timing of these celebrations could not have been better. This week through the Zanzibar International Film Festival, Zanzibar is hosting the Festival of the Dhow Countries. The festival will feature films, videos, theatre, music, dance, and other art forms and celebrates the shared cultural heritage of the people of the dhow countries.

Mr Chairman, I understand that this conference is part of the celebrations to commemorate the twentieth anniversary of the founding of the Institute in 1979. I wish to join with you in these celebrations and I wish you many more such happy anniversaries.

When in 1979 Tanzania decided to establish a centre of excellence for marine sciences, Zanzibar came forward and offered to host such an institution. This was in recognition of the fact that Zanzibar, being an island and surrounded by the ocean, was better placed in the country to serve as a host for the Institute. However, more importantly, we also recognised the valuable contribution that marine sciences can provide towards the nation’s socioeconomic development. Given the valuable contribution that IMS has made in terms of scientific research, education and various other services, I believe we have been proven right.

The Zanzibar Islands have a long-standing and critical connection with the marine environment. The islands themselves are actually ancient reefs. Fishermen and other coastal communities have historically obtained their livelihood and resources from the sea. Even the Stone Town where this hotel is located is built of ancient coral rock and construction over the rest of the island utilises lime derived from ancient coral stone. In addition, tourism in Zanzibar is largely beach and marine based and thus depends directly on marine resources and their diversity.

Mr Chairman, our people look upon us, the Government and you the intelligentsia, to help solve some of the problems that are facing our nation. Most of our people are poor. We are also concerned with the growing environmental degradation and the
wanton destruction of our resources, including marine resources. Obviously these factors are intimately linked with one another. We urgently need to settle these problems to ensure a better life for our people. As Dr Sridath Ramphal, the former Secretary General of the Commonwealth observed, and I quote:

...simply to tell those at the margin of existence not to cut down the forest or not to have many children, when they see both as necessary for their survival, is not only insensitive to their predicament, but downright provocative. We can only ask them to help in conservation efforts if they are linked to their own survival.

Consequently, I urge you to carefully set your research priorities to reflect these needs so as to provide a solution to these problems facing our people. I therefore humbly wish to make the following suggestions:

**Poverty alleviation**

As I have mentioned earlier, poverty is a great concern to us and I counsel your cooperation to focus your research efforts towards alleviating this problem. The ocean offers a lot in terms of resources, both living and non-living. Given the large expanse of ocean that has come under our jurisdiction under the terms of United Nations Conference on the Law of the Sea (UNCLOS), I believe that the ocean can contribute significantly towards easing the chronic poverty that is afflicting our society. I therefore suggest that you critically investigate ways through which we can utilise the rich resources of the sea to help us solve this issue. In recognition of this fact, both the Zanzibar Agricultural Policy and Environmental Policy have recognised the significance of the marine environment in terms of its importance in social and economic development.

Mr Chairman, here in Zanzibar, it has been shown that coastal tourism and algal culture can significantly contribute to the country's economic and social development. Algal culture, in particular, has changed for the better, the living standard of thousands of people on the islands. More needs to be done in developing other alternative economic activities such as fish farming.

**Environmental control**

Mr Chairman, the environment is a major national concern, and the marine environment is no exception. This ecosystem is also among the hardest hit by environmental degradation in our country. Many of our major coastal cities experience pollution especially that emanating from municipal sources. This problem is bound to increase in the coming years, given the continued migration of people from the hinterland with the subsequent increase in the discharge of untreated waste into the coastal waters. Some of our coastlines experience severe erosion problems that in some cases threaten to undermine our efforts to develop tourism along our coasts. It appears that in many cases this problem is entirely caused by man himself through the clearing of mangroves,
dynamite fishing, beach sand mining and through other destructive practices. This area of concern warrants your special attention.

**Resource use conflict management**

Mr Chairman, we all know that there is no real development where there is no peace and harmony. Our country has witnessed increasing resource use conflict, which in some cases has led to the denial of our people their only means of sustenance. Unplanned coastal development whether for tourism development or otherwise has also denied coastal communities space to carry out their traditional activities thus leading to space conflicts. If we are to assure sustainable economic development we should nurture a culture of harmony among ourselves and between ourselves and other countries within the region. It is imperative therefore that we put emphasis on research that looks into ways that mitigate these problems, particularly on how best the ever decreasing amount of space could best be used to accommodate different socioeconomic activities.

**Cooperation with neighbours and the region**

One Swahili saying reads ‘Bahari haina mipaka’, that is ‘the ocean has no borders’. Very often this has been practically proven right. We have seen activities that emanate from one coastal country spreading into another. We know that there are a number of marine species, such as marine turtles, that breed in one country but spend most of their lives in another. That is, they are essentially trans-border. Furthermore, for centuries it has been common for our local fishermen to criss-cross national borders to carry out their fishing activities. These issues cannot be dealt with by one nation alone and are only some examples of cross border issues that call for bilateral and even regional co-operation in terms of research partnership. Hence, we must put emphasis on collaborative research that encourages the exchange of information and research results for our mutual benefit.

Mr Chairman, I have pointed out some crucial area of research that I urge you to consider. I would just like to add that the private sector has a large role to play in facilitating marine research. Companies, such as pharmaceutical companies, can help fund research on marine natural products, for example, that can be of their benefit as well. This line of cooperative research is worth investigating.

Mr Chairman, I understand that one of the expected outcomes of this conference are suggestions for future research strategies and research approaches. I hope that you will look critically at my suggestions and I hope that they will help you to chart out a new path for IMS, the country and the region at large. Mr Chairman, dear participants, there is no need to remind you that our country is poor, very poor. Therefore, when you are prioritising your research agenda, that should be taken into consideration. Priority should be accorded to research geared towards solving problems on the ground.

Finally I wish to pay a public tribute to all those who have made this conference possible. Special thanks go to Sida, CIDA and USAID for their financial support. I also wish to thank the Institute of Marine Science for organising this conference.
Mr Chairman, with those few words please allow me to formally declare this Conference on Advances in Marine Science in Tanzania open. I wish you all successful deliberations during the coming four days.
The challenges of integrating marine sciences with coastal management in the western Indian Ocean region

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ABSTRACT

About 30% of the 100 million inhabitants of the western Indian Ocean (WIO) region reside in the coastal strip and are heavily dependent on goods and services provided by oceans and coasts. Coastal areas provide food and resources which support the economies of coastal states of the western Indian Ocean such as fisheries, shipping, petroleum exploitation, seabed mining, energy and tourism. Coastal and marine areas house a bounty of biodiversity and the oceans are also responsible for balancing the extremes of climate conditions. However, our efforts to effectively manage the use of coastal resources in a sustainable manner are constrained by inadequate knowledge in the ecosystems and inadequate capacities to generate the knowledge. This is compounded by the lack of prioritisation of issues and integration of coastal and marine management and marine science in most maritime states.

This paper examines the challenges in integrating ecosystem-level coastal and marine science with integrated coastal and marine management, as well as the opportunities for bridging the gap between science and coastal management in the western Indian Ocean. The integration of ecosystem management and ecosystem science will ensure the sustainability of the marine and coastal resources.

INTRODUCTION

Today, this Conference is organised to mark the 20th anniversary of the Institute of Marine Sciences (IMS). We should also be reminded that the IMS resides at the premises of the former East African Marine Fisheries Organisation (EAMFRO)—established about 40 years ago—of the former East African Community. During these four days the conference will receive presentations demonstrating significant advances in marine sciences both in terms of capacity and information. My own presentation sets the basis for our aspirations in advancing the scientific knowledge on marine ecosystems.
THE GLOBAL CHALLENGE

The ocean covers more than 70% of our planet and plays an important role in many ways. The bounty of goods and services provided by coastal and marine ecosystems attracts population increase in coastal areas. These goods and services include food that to most coastal societies is the only source of protein. Coastal areas support the economies of many maritime nations through fisheries, shipping, petroleum exploitation, seabed mining, energy and tourism. In addition to these tangible benefits to humanity, coastal and marine ecosystems perform critical ecological functions.

The coastal strip is where we live. A significant proportion of the world’s human population resides in the coastal strip not exceeding 150km from the shoreline. For example, it is estimated that 60% of the world population lives in the coast and about 70% of the world’s cities with populations exceeding 2.2 million are near tidal estuaries. It is also estimated that the population of the coastal zones will double by the year 2020 (Olsen et al., 1999).

However, the resources that we depend on are declining at an unprecedented rate and the environment that we enjoy is degrading faster than we can ever imagine (Box 1). There has been a long-standing understanding that users have an open access to marine resources. In the early days, the presence of people did not harm coastal and marine environments. The uses of marine and coastal resources, mainly fisheries, caused some local environmental changes without threatening sustainability. Today, we are witnessing increased uses of coastal and marine resources as well as growing beach erosion and amplified sea level changes. Without linkage between good science and proper management, these uses and natural changes will impact on the environment and create competition and conflict.

**Box 1: Vital and critical statistics from ocean fisheries**

- 70% of the world’s commercially-important marine stocks are fully fished, overexploited, depleted or slowly recovering.
- Some staple species such as the northern cod and Atlantic halibut have been excessively fished to commercial extinction.
- Worldwide, governments pay an estimated $54 billion per year in fisheries subsidies to an industry that catches only $70 billion worth of fish.
- Contemporary fishing practices kill and waste 18–40 million metric tonnes of unwanted fish, seabirds, turtles, marine mammals and other ocean life annually and this represents about one-third of the total world catch.

MARINE AND COASTAL PRESSURES AND OPPORTUNITIES IN THE WIO REGION

The coastal and marine pressures confronting the WIO Region include population increase, poverty, environmental degradation, declining coastal and marine resources, poor governance and lack of appreciation of coastal and marine resources (Ngoile et al., 2001).

It is estimated that more than 30% of the 100 million inhabitants in the region are living in the coastal zone. In 1992–93, the estimated GNP per capita of the WIO Region ranged from $80 (Mozambique) to $330 (Kenya) making it one of the world’s poorest regions. The combination of poverty, rapid population growth and poor understanding and management of coastal resources, particularly in the mainland countries and Madagascar, has resulted in a number of environmental and resource-use problems, including habitat destruction, over fishing, human-induced coastal erosion and flooding, and marine pollution mainly from land-based sources.

The western Indian Ocean, compared to the other oceans, is not particularly productive with respect to fisheries. Approximately three million tonnes of fish, crustaceans and molluscs are caught in the western Indian Ocean each year. The total fisheries production within the region increased by 72% from 1980 to 1990. However, annual fish consumption per capita has decreased from 3.7 to 1.9kg per year over the same period (Ngoile and Linden, 1998). The fisheries productivity is further reduced by the use of destructive fishing practices and habitat destruction, particularly that of coral reefs.

Several land-based activities are impacting on marine ecosystems. Land reclamation projects have filled extensive intertidal areas, particularly on islands, where flat coastal land is in high demand. In Victoria, Seychelles, for example, the airport, two ports and relatively large residential areas and roads have been built on reclaimed land, as are the main port and coastal industrial zones in Mauritius. Beaches and sand dunes in Mozambique and Tanzania are mined for construction materials and black sand minerals, causing direct habitat destruction and subsequent coastal erosion. Coastal vegetation, including the mangrove forests, is being cut and degraded in many areas throughout the region.

The industrial sector is not strongly developed in most of the region (except in South Africa), and focuses primarily on the processing of agricultural products, petroleum and other goods (e.g. textiles, fertilisers) for domestic consumption. In the coastal zone, these industries are clustered around the larger cities and ports, such as Mombasa, Dar es Salaam and Maputo. In Mauritius, the Export Processing Zone has attracted considerable foreign investment, and manufacturing is now the largest component of the island’s GDP (24%). Wastes from these industries tend to be organic- and nutrient-rich, and are commonly discharged to sewers or directly into rivers and coastal waters without pre-treatment. Similarly there is no treatment of domestic wastes in the coastal
cities and rural areas of the region. Many coastal ecosystems are also damaged indirectly by hydrologic alterations to rivers.

Governance on coastal and marine resources is characterised by the absence of effective and integrated coastal and marine management, which has resulted in growing environmental problems in all the countries of the WIO region.

In spite of these pressures, however, the western Indian Ocean region has great potential for development, which if tapped in a sustainable manner, could lead the region to economic and social prosperity. These include:

- **Development of tourism.** There are considerable areas, which are relatively undisturbed and which have pristine coral reefs, less exploited fisheries, beautiful beaches and pristine stands of mangrove forests. These areas are found in southern Tanzania, northern Kenya, Mozambique and Somalia. These areas present great potential for the development of tourism.

- **Mariculture.** There are significant areas suitable for the development of mariculture.

- ** Fisheries.** Most of the fisheries in the region is artisanal and as such has not succumbed to massive overcapitalisation. Fishing pressure is only experienced in nearshore waters, which can be reached by the traditional crafts, most of which are wind-propelled.

- **Hydrocarbons and minerals.** Large deposits of hydrocarbons have been discovered along the coast of southern Tanzania and black sand minerals are found along the coast of Kenya.

**ECOSYSTEM-LEVEL SCIENCE**

Integrating natural and socioeconomic scientific knowledge as well as analysis of management structures are key components for advising the successful implementation of sound policies, development plans and management strategies for the sustainable use of marine and coastal resources. Box 2 provides the basic components of the scientific research required to inform integrated coastal and marine management (GESAMP, 1998; Olsen et al., 1999) and Figure 1 shows the processes for integrating science with coastal and marine management. The scientific tools, which are particularly useful in generating information relevant to coastal management, include resource survey techniques, hazard and risk assessments, modelling, economic valuation and evaluations and analysis of legal and institutional frameworks for coastal management.

Traditionally the scientific approach employed in marine and coastal research has concentrated on the state of natural ecosystems, i.e. identifying the damage and disturbances to the ecosystems. Therefore, the scientific advice has always been biased towards the natural ecosystem and the management measures/actions have lacked the human dimension. Whereas natural sciences are vital for the understanding of the functioning of ecosystems (*state variables*), socioeconomic sciences including the analysis of governance structure are essential to comprehending patterns of human behaviour.
Box 2: Components of ecosystem based research for supporting integrated coastal and marine management

The following research components are important in ensuring ecosystem approaches to gathering information in support of integrated management of marine and coastal resources.

1. **Assessment of resources and the environment**
   
   (a) Assessment of ecosystem health and conditions:
   - marine biodiversity and biogeography;
   - populations, species, habitats, ecosystems;
   - fragile and sensitive ecosystems;
   - coral reefs, mangroves, coastal wetlands, coastal lagoons, estuaries, seagrass beds, small islands;
   - threatened and endangered species.

   (b) Resources:
   - natural resources (fisheries, mangroves, seaweed);
   - non-living resources;
   - services, e.g. transport, recreational.

   (c) Threats:
   - land-based activities—coastal development, coastal and river basin agriculture and livestock, tourism, river impoundment, deforestation;
   - ocean-based activities—impacts associated with marine transport, seabed mining, hydrocarbon exploitation (ocean based oil drilling).

2. **Assessment of socioeconomics of coastal stakeholders**

   (a) Assessment of socioeconomic and demographic patterns for:
   - safeguarding livelihoods;
   - equitable sharing of proceeds from resources uses;
   - capturing indigenous knowledge that is then used in policy, planning and management process;
   - ensuring transparent tenure systems;
   - assessing the development alternatives, including cost-benefit analysis.

3. **Assessment of the effectiveness of the governance**

   (a) Assess existing policies and management mechanisms for their effectiveness.

   (b) Select appropriate approaches to improve the management, e.g. ICM, MPAS, LMES.

   (c) Assess the level of inclusion of the following characteristics:
   - community/stakeholder/private sector involvement
   - cooperative management
   - collaborative management
   - cross-sectoral and multidisciplinary management actions based on scientific information

   (d) Development of policy, management plans, guidelines and legislation.

   (e) Synthesise and document successful ICM experiences and facilitate their replication so as to avoid ‘reinventing the wheel’. This will save time and money as well as enhancing the sharing of experiences.

   (f) Promote the referencing of successful ICM experiences during regional and global debates and negotiations for the best code of conduct leading to the conservation and sustainable use of marine and coastal resources.

Source: Ngoile et al. (2001).
Managing coastal and marine resources for sustainability

Time-scaled processes for achieving long term goal → Sustainable economic and ecosystem functional benefits

Analysis of issues (National and T/Boundary)

Condition of resources and environment

Socioeconomic assessment

Assessment on existing governance

Synthesis and integration

Governance adjustment

Implementation of policy and management action

Monitoring and evaluation against a set of indicators:
- condition of resources and environment
- socioeconomic assessment
- assessment on existing governance structures

Analysis of issues (National and T/boundary)

Prioritisation of required assessments

Assessment reports

Management options

Policy and management decisions

Time stepped adjusted incremental actions

Figure 1. Integrating science and coastal management
that cause ecological damage (*pressure variables*) and to finding effective solutions (*management measures*) (Olsen et al., 1999). Scientists and managers must work together to reach an agreement on the scientific work needed to address priorities, which are essential for and guide management.

The existing information base on marine sciences in the WIO region is inadequate and cannot inform public policy and management processes. The state of the information is further aggravated by the fact that most of it exists as grey literature under the custody of government departments and not in universities and public libraries.

Another dimension of hindrances to the successful development of science-based marine and coastal management in the WIO region is associated with inadequate communication between resource users, scientists, planners and policy makers. The lack of coordination between different users, together with lack of appreciation on the dynamics of the coastal resources has resulted in highly sectionalised policies and management strategies that have little consideration to intersectional issues and the natural linkages between different resources.

**THE EVOLUTION OF MARINE SCIENCES IN THE WESTERN INDIAN OCEAN**

The history of marine sciences in the western Indian Ocean dates back to the 1960s during the Indian Ocean Expedition. To date the Expedition is the most comprehensive marine scientific venture ever undertaken in the region. The expedition has provided the knowledge base on the physico-chemical-biological processes, especially how these are influenced by the Monsoons. In the 1970s marine research in the region concentrated on fisheries and related sciences. The emerging independent states of eastern Africa prioritised the development of fisheries resources to meet protein requirements of coastal populations as well as to provide foreign exchange earnings.

The Food and Agriculture Organisation of the United Nations (FAO) has been assisting eastern African states in their endeavour to sustainably develop marine fisheries for over two decades (Insul et al., 1995). Estimation of the level of fish stocks can only be achieved through surveys and catch landing statistics. Poor fisheries statistical collection in the countries of the region limits the accurate assessment of stocks and reliability of estimates hence the level of exploitation can only be guessed at. Secondly, most fisheries resources have open access, a condition that leads to competition in the exploitation of resources without due regard being paid to sustainability. FAO has addressed these problems by providing support for resource surveys and building capacity and tools for national fisheries statistics.

During 1982/84, the Norwegian research vessel *Dr Fridtjof Nansen*, conducted fisheries surveys in Mozambique, Tanzania, Madagascar and Kenya. Scientists from these countries joined scientists from Norway in data analysis and presentation. The results of the surveys were presented to the various governments through national
workshops. There is a potential for increasing the current level of fish production through the improvement of fishing and preservation techniques (Iversen and Myklevoll, 1984). This could be achieved through training and education as well as introduction and development of new methodologies based on those developed in Asia and the Caribbean. In addition, Bianchi (1992) analysed the data collected during the surveys and has established the pattern of distribution of demersal fish species in the western Indian Ocean.

Several mechanisms, which provide a regional setting for the discussion and exchange of national experiences on the scientific information and management of coastal and marine resources in the western Indian Ocean region, have been developed since the mid 1980s. Regional mechanisms of this type include the East African Action Plan (coordinated through UNEP’s Regional Seas Programme and the Nairobi Convention), the Western Indian Ocean Fisheries Sub-Commission, the Intergovernmental Oceanographic Commission’s Regional Committee for Cooperative Investigation in the North and Central Western Indian Ocean (ICOCINWIO) and Western Indian Ocean Fisheries Sub-Commission, a subsidiary body of the Indian Ocean Fisheries Commission. The Western Indian Ocean Fisheries Sub-Commission is currently coordinating national mechanisms for the management of tuna stocks within the region.

PRESENT REGIONAL MARINE SCIENCE INITIATIVES IN THE WIO REGION

The current (1990s) marine scientific activities in the region are carried out under the concept of Integrated Coastal and Marine Management (ICM). The ICM approach was concretised and endorsed as appropriate for the sustainable use of coastal and marine resources during the processes leading to the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil. The application of ICM in the WIO region was subsequently reviewed in the region during the Workshop and Ministerial Conference on Integrated Coastal Zone Management in Eastern Africa, including the Island States, held in April of 1993 in Arusha Tanzania (Linden, 1995).

During the workshop, experts discussed the environmental problems of the region’s coastal zone and formulated a number of technical recommendations. Reflecting the multiplicity of coastal issues, the following approaches were proposed: review of national policies to enhance sectoral integration, inclusion of ICZM philosophy in national planning processes, institutionalisation of cooperative management and a multidisciplinary approach in conducting research.

The participating ministers discussed the recommendations presented by the experts and they formulated and signed the ‘Arusha Resolution’; a policy statement calling upon the states of the WIO Region to give emphasis to sustainable development and integrated management of coastal areas for the primary benefit of coastal communities. The Arusha Resolution emphasised the need for integration of all issues,
involvement of all players in the planning process, coordination between sectoral agencies, integration between science and management and application of cooperative management during the implementation of ICM. The Arusha Resolution directed the scientific community and called for an inter- and multidisciplinary approach to research in order to provide the required knowledge for ICM.

The Arusha Conference has stimulated the development of a number of coastal and marine programmes. Under the East African Action Plan, several programmes have been implemented, including EAF/6, which focuses on the assessment of land-based pollution and EAF/5, which specifically addresses coastal zone management. Within the framework of EAF/5, ICM pilot projects are being implemented by national institutions in Kenya, Tanzania and Mozambique, with support from the United States Agency for International Development (USAID) and United Nations Environment Programme (UNEP).

IOCINCWIO is a regional intergovernmental committee that meets every three years to assess scientific achievements and formulate/prioritise areas of marine research to be carried out in the region. The Regional Marine Science Program for Eastern Africa supported by Sida-SAREC undertakes research and training activities aimed at providing the capacity and scientific knowledge required to formulate management measures for the sustainable use of coastal resources. The IOC and Sida-SAREC processes have encouraged and supported the development of a regional scientific non-governmental organisation—the Western Indian Ocean Marine Science Association (WIOOMSA).

CONCLUSION

The western Indian Ocean region is at crossroads, where on the one hand there are pressures on the coastal environment, but which exist in 'hot spots' and on the other, great opportunities for sustainable coastal development. Unfortunately the pressures are increasing at an alarming rate. Recognising the complexity of coastal and marine ecosystems, we need to move as rapidly as possible to ecosystem level science and management. ECOSYSTEM SCIENCE AND MANAGEMENT considers both human activities and natural dynamic processes as one integrated system.

REFERENCES


Highlights of the evaluation of the Sida/SAREC Regional Marine Science Program

Per Brinck
Swedish International Development Agency (Sida)

EXECUTIVE SUMMARY

This evaluation focuses upon the most recent three years of the three Sida/SAREC marine science program in East Africa. These are: the Bilateral Programme for Mozambique (initiated in 1985), the Bilateral Programme for Tanzania (initiated in 1990) and the Regional Programme (initiated in 1993). This evaluation assesses these initiatives in terms of the current maturity of coastal governance in the region and capacity in the marine sciences.

The three programmes are closely interrelated, particularly in Tanzania, and their combined impact has produced significant advances towards the goal of a diversified resident capacity in the marine sciences that can contribute towards advancement in effective management of coastal ecosystems. Investments in the natural sciences have greatly increased and diversified resident capabilities. Investments in the social sciences have been more modest but here, too, notable progress has been achieved. Activities designed to promote coastal governance have been directed primarily at high level policy-makers and have successfully catalysed a rapidly growing number of integrated coastal management initiatives at the regional, national and local scale.

CAPACITY BUILDING IN THE MARINE SCIENCES

During the 1990s, the central strategy of both the Bilateral and the Regional programmes has been to fund the graduate degrees of East African scientists. While only four graduate degrees had been completed by 1996 in the Sida/SAREC marine science programmes, today 26 MSc candidates and three PhD candidates have earned their degrees. Twice this number of MSc candidates and 18 PhD candidates are ‘in the pipeline’. Nearly all the students supported by the Regional Programme expect to graduate in the year 2000. It may be concluded that a critical mass of well-trained marine scientists is now present in the region. In some cases, their home-laboratories are sufficiently equipped to support sustained research activities but others still require institutional support.

While the emphasis on thesis research is achieving the central goal of building resident research capability, this approach has several limitations: research topics are being selected primarily to meet academic criteria and reflect the individual interests of major professors and their students; and the links to priority resource management questions are weak and little has been achieved in terms of interdisciplinary research.
explicitly structured to address urgent societal and resource management issues. However, the short courses and workshop sponsored by the Regional Programme have done much to encourage exchange among scientists and discussion on how to link science to resource management issues, and to assess initial local experiments in the practice of integrated coastal management. Many of the East African scientists whose graduate training was supported by this programme are actively engaged in coastal management initiatives that are now being supported by a diversity of institutions.

INSTITUTION BUILDING

The program's most notable achievement is the transformation of the Tanzania Institute of Marine Sciences (IMS) of the University of Dar es Salaam into an internationally recognised institution with a permanent staff of 17 researchers of which 10 have PhDs. IMS is attracting funds from a diversity of sources, hosting visiting scholars from many nations and is making significant contributions to public policy and resource management in Zanzibar, Tanzania and the region. Similarly, the smaller but important Inhaca Research Station has been refurbished and equipped and is supporting the research activities of both national and foreign scientists. The Departments of Botany and Zoology/Marine Biology as well as the Department of Sociology and Anthropology of the University of Dar es Salaam (UDSM) and the Institute of African Studies at the University of Nairobi have also benefited from the programme and have been strengthened. In Mozambique, the Bilateral Programme has nurtured a dedicated group in the Biology Department at the Eduardo Mondlane University (UEM).

Significant benefits have also flowed to the participating Swedish university departments and institutes, many of which now have well-established partnerships with their counterparts in East Africa. The marine science programmes have brought to collaborating Swedish institutions a flow of graduate students, new research opportunities, salary support and encouraged frequent travel in the region. These opportunities are complemented by the Swedish Applications Programme and the Minor Studies Programme that encourage both established researchers and undergraduate students to pursue their interests in developing nations. Together, these programmes amplify the research capacity that is now available to support coastal management initiatives.

INSTIGATING INTEGRATED COASTAL MANAGEMENT IN THE REGION

In the early 1990s, the Regional Programme sponsored pioneering work to instigate a dialogue among high level policy-makers on the societal issues posed by rapidly mounting pressures on coastal ecosystems and the need for national coastal management initiatives. The 1993 Arusha Conference catalysed the first high level political commitments to integrated coastal management. The formulation and progress of coastal
management initiatives sponsored by various institutions as well as the results of scientific research have been thoroughly documented and widely disseminated through an outstanding series of documents and in articles published in the international journal *Ambio*. Recognising the growing number of research and coastal management initiatives in the region, Sida/SAREC investments need to be carefully targeted on approaches that capitalise upon its dedication to long-term capacity building. Future activities designed to encourage good management practices in the region should draw from the conceptual frameworks emerging from worldwide experience in coastal management.

**RECOMMENDATIONS FOR FUTURE INVESTMENTS IN THE MARINE SCIENCES**

In the judgement of the evaluation team, the Sida/SAREC marine science programmes have reached an important point of articulation. While the central capacity-building goal should be maintained, we recommend making adjustments to the programme’s implementing strategies in order to take full advantage of the major achievements gained in the past decade. We therefore recommend that the next phase of the marine science programmes be viewed as a transition to a second generation effort in which resource management and quality of life issues will be addressed more directly and the local ownership of governance initiatives sponsored by the Regional Programme will be enhanced.

Specifically, we recommend that a clearer differentiation be made between building strategies and the research activities sponsored by the Regional and Bilateral Programme. The Bilateral Programme should continue to give priority to the support of graduate studies while the Regional Programme should harness the capabilities now in place by sponsoring interdisciplinary research projects on priority coastal management topics. In the future, graduate studies in the marine sciences supported by the Bilateral Programmes should be guided by:

- A needs assessment that would guide setting priorities for support to graduate students in specialisation in the social and natural sciences. Such priorities should account for the projected employment opportunities for professionals with MSc and PhD degrees in their home countries.
- Giving priority to thesis research that is conducted as an element of interdisciplinary projects in pilot coastal management sites or on socially and environmentally important topics.
- Giving consideration to sponsoring an Honors Programme in coastal management that would introduce the next generation of natural and social scientists to the principles of coastal management and interdisciplinary research.

A new administrative structure should be developed for the Regional Program. We recommend that future activities include:
- A competitive grants programme organised as a two- or three-year funding cycle designed to generate the information and knowledge required by the formulation of coastal management initiatives.
- A coastal ecosystem forecasting and monitoring programme directed at a few carefully selected indicators of anthropogenically induced coastal ecosystem change.
- Regional networking activities designed to address a few carefully targeted priorities that link public education and extension activities to the research activities sponsored by the program.
A Tanzania–Canada marine relationship: The University of Dar es Salaam–Memorial University of Newfoundland Cooperation Programme

A. B. Dickinson

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INTRODUCTION

Canadian involvement in marine science development in Tanzania in recent years began with the secondment in the mid-1980s of institutional and government personnel to training and education programmes in Canada. Of particular note was their involvement in those short courses implemented by the International Oceans Institute (IOI) at Dalhousie University and the postgraduate opportunities funded by the now defunct International Centre for Oceans Development (ICOD) at, for example, Dalhousie University and Memorial University of Newfoundland (MUN).

Relationships between MUN and the University of Dar es Salaam Institute of Marine Sciences (UDSM/IMS) began following the attachment to IMS of a MUN graduate as a Canadian University Services Overseas (CUSO) volunteer in 1988. The volunteer initiated correspondence with MUN’s international office as to how MUN might assist in the development of IMS, previously the headquarters of the East Africa Marine Fisheries Research Organisation (EAMFRO). Relationships were therefore developed with the then recently appointed (1988) Director of IMS, Dr Magnus Ngoile. Funding for a project development mission was obtained from a travel microfund operated by the Canadian International Development Agency (CIDA). This provided the opportunity for Dr A.B. Dickinson, then Senior Project Officer of MUN’s Canadian Centre for International Fisheries Training and Development (CCIFTD), and Mr Paul MacLeod, a development support communications specialist then attached to the now defunct Don Snowden Centre for Development Support Communications of MUN, to visit both the University of Dar es Salaam and the Institute of Marine Sciences in 1989. Dr Dickinson is now Associate Executive Director of MUN’s International Centre, and continues as the Canadian project coordinator. Mr MacLeod runs his own media company (Anigraph Productions) in Newfoundland.

As a result of this visit, and in collaboration with Dr Ngoile, an institutional linkage proposal was written and submitted to the 1989 competition of the CIDA Educational Institutions Programme (EIP). This was approved in July 1990 for a five year period, with $Can 874,514 funding from CIDA. The cooperation project ‘Development of a Fisheries Resource Extension Unit in Tanzania’ thus began. Its goal was “to contribute
to diversification and conservation of the Zanzibar artisanal fishery,” with the more immediate purpose of “strengthening the fisheries extension capability of the Institute of Marine Sciences, Zanzibar”. An outline of project activities and outputs follows.

**ORIGINAL PROJECT OUTPUTS**

The project originally set out to achieve the following outputs:

(a) Two IMS scientists (one female and one male) trained to Master’s/Diploma level in marine management, or to Diploma level in aquaculture at the Newfoundland and Labrador Institute of Fisheries and Marine Technology (the Marine Institute). Both to be subsequently trained at MUN/IMS in associated extension methods.

(b) Four supporting technicians and all other IMS scientists trained in extension methods and support services.

(c) Location at IMS of appropriate equipment and infrastructure for a fisheries extension resource centre.

(d) Thirty women (two from each fishery officer region) trained in development support communications.

(e) Fifteen regional fisheries officers and appropriate personnel from government, parastatal and university departments trained in extension and development support communications.

(f) Various appropriate extension/marine management curriculum/audiovisual presentation and support materials.

(g) Two aquaculture technicians.

**ACTUAL PROJECT OUTPUTS**

These are grouped under sectoral headings as below. Although (d) and (e) of the original outputs were not achieved, all others were, and at a level in excess of that originally planned. In addition, as the project evolved over its (10-year) operational cycle, other initiatives were undertaken to complement or extend those originally specified. Thus, what was actually achieved was far more than proposed, especially with regard to formal and non-formal education.

**EXTENSION**

At the time the project was conceived, the IMS did not have any component formally concerned with the delivery to the community of information on fisheries, marine science and environmental issues. To develop this capability was considered the central function of the project.
Establishment of the Marine Education Extension Development (MEED) Unit

This was established through the project in 1992 as a new operational unit of IMS, with the objective of providing a public awareness component to institutional activities. The Unit’s responsibilities include the production of print and video materials, and development and implementation of outreach initiatives to schools and the general public. MEED is under the guidance of a research/administrative staff committee, and is now a sustainable component of IMS.

Establishment of a media unit within MEED

The use of small-format video is considered an important tool for supporting development projects and raising public awareness, especially where literacy levels might be low. Three video production personnel were therefore transferred to MEED on long-term secondment from Zanzibar Television (TVZ). All thus had a degree of experience, and the producer had also received training in East Germany in the early 1980s. They are now employed on a full-time permanent basis by IMS.

Provision of video production equipment and training

The Canadian private sector (Mr Paul Macleod, Anigraph Productions, St John’s) provided substantial training to develop the capabilities and operational flexibility of the production personnel referred to in (b) above. All were trained on project video equipment (sVHS edit suite, cameras, etc.) purchased by the project from Singapore. In addition, they were encouraged to develop and implement charge-out rates and procedures for contracting the work of the media unit out to other funding agencies or institutions that share common objectives. This has been successfully accomplished, and should continue to make a significant contribution to the sustainability of MEED. A list of videos produced in English and/or Kiswahili is appended (Annex 1).

The project has thus achieved its central objective, namely the development of a potentially sustainable resource unit at the IMS. This has a wider scope of activities than originally called for, being not just simply a ‘fisheries extension resource unit’ but rather one capable of addressing the wider marine-related education and extension needs of Zanzibar and the region.

GRADUATE EDUCATION

Activities undertaken under this rubric were also modified to reflect evolving local needs and funding sources. When the project began, there was only one person with a PhD (Dr Magnus Ngoile, Director) on the staff of IMS. Subsequent initiatives by Sweden and Canada have increased this number to twelve. In addition, others have been upgraded to Masters level. The project has therefore made an important contribution to building the human resources capacity of the UDSM/IMS, and thus their local and regional impact, as follows.
1. In view of the lack of local and regional capability in library and information science and technology, especially with a marine emphasis, one IMS staff member, Ms Edna Nyika, was funded for two years (1995–1997) to study for an MLS (Masters in Library and Information Science) at Dalhousie University. She is now working on database organisation at IMS, and with the Institutional Planning office of the UDSM to develop ideas for introducing information technology initiatives into the university curriculum and teaching processes.

2. One IMS technician, Ms Rose Sallema, was also funded (1995–1997) to pursue an Advanced Postgraduate Diploma in Aquaculture at the Marine Institute of Memorial University. Ms Sallema returned to work at IMS as an aquaculture technician.

3. In a related use of matching CIDA funds, one IMS staff member, Mr Amani Ngusaru, was also funded (1994–1998) to pursue a PhD, physical oceanography at MUN through the CIDA/MUN/Marine Science Scholarship Programme operated by MUN’s International Centre. Mr Ngusaru successfully defended his thesis in September 1999.

4. Not all IMS staff working towards a PhD are doing so overseas with donor funding. Two senior IMS research fellows, Nariman Jiddawi and Jude Shunula have been working towards PhDs from the University of Dar es Salaam, the former on fish biology and the latter on mangrove energetics. Both had problems completing their work due to, e.g. lack of recent literature, difficulties in analysing data, and thesis writing methods. The project was able to assist them in overcoming these problems by providing the opportunity for one (Dr Shunula) to work at MUN under the guidance of Dr Alan Whittick, Professor, MUN Department of Biology. This relationship continued in Zanzibar. Editorial assistance was also given to Ms Jiddawi, and external examination of her PhD thesis carried out by Dr R. Haedrich, also of MUN’s Department of Biology. These initiatives were not specified in the original project objectives, but were considered to be extremely worthwhile for capacity building.

In summary, the sustainable graduate education component of the project has proved very satisfactory, although modified somewhat in detail due to ongoing locally identified needs.

**RESEARCH AND TEACHING COOPERATION**

This aspect of the project was largely accomplished between Drs Whittick and Shunula, and evolved from the relationship which helped Shunula to complete his PhD. The research component was primarily field-oriented in Zanzibar, although Shunula’s visits to MUN allowed him to access library information not available in Zanzibar. In addition, Dr Whittick also benefited substantially from this relationship by gaining substantial new knowledge on tropical marine ecosystems appropriate to his course development and teaching at MUN, thus conforming both to the true spirit of partnership and to the
current CIDA institutional programme objective of internationalising the Canadian institution. The relationship also provided Dr Shunula with the opportunity to co-author several papers and presentations, raising his regional visibility as a mangrove biologist and contributing to an opportunity to participate in three European Union regional mangrove projects, including supervision of two graduate students from the Universities of Liverpool and Florence. Publications and presentations of the Shunula/Whittick relationship are:


6. Whittick, A. 1996. (a) Factors affecting distribution of marine algae. (b) Life history studies on seaweeds. Presentations to Botany 4000 class (Dr Shunula) at the University of Dar es Salaam.

PUBLIC AWARENESS

Many marine and coastal environments and their species are under threat from human activities such as over-fishing, deposition of pollutants and coastal zone deterioration. This is the case in Zanzibar, and in the western Indian Ocean in general. Therefore, it is a responsibility of government institutions and agencies to develop mechanisms and programmes to inform the general public of the relevant issues, and thus hopefully reverse some of the damaging trends. It was for this reason that it was decided in the original project document to develop an extra component to the scientific activities of the IMS, namely the development of the MEED unit and its video production capability.

Some 35 videos have been produced by the unit, mostly on local environmental and institutional issues. Many were done in Kiswahili and translated into English. Some were made using external funds from agencies/institutions such as UNESCO, IOC, KMFRI and Sida/SAREC. Since the primary objective of MEED is to provide a public awareness component to the activities of IMS, significant importance was placed on developing procedures for showing the videos using a mobile unit. Although initially slow
to occur due to lack of videos and logistic issues, this has improved in recent years following the spread of television both in Zanzibar and on mainland Tanzania. Consequently, it has been possible to screen videos on, e.g. TVZ, DTV and ITV. A screening programme for villages was also implemented during 1997 as part of local activities for the International Year of the Coral Reef and during the Zanzibar International Film Festival (ZIFF) 1998. In addition, IMS makes substantial use of the videos as an information source for visiting local and international educational groups.

It also became obvious during the project that there was virtually no print information locally available to schools, teachers and the general public on the island’s species and environments, and their interactions. Therefore, in addition to the MEED producing videos, a start was made on the production of a series of small booklets written in relatively non-scientific terminology and directed to the target groups identified above. These booklets have been provided to the Ministry of Education of the Government of Zanzibar as curriculum support materials, and to the National Teachers’ Resource Centre (established with World Bank/DANIDA funding) at Nkrume Teachers’ Training College in Zanzibar. Copies are also available at the IMS for use by visiting students, and have been widely distributed throughout the region by being made available to participants in the Institute of Marine Sciences 20th Anniversary (1979–1999) Symposium ‘Conference on Advances in Marine Sciences in Tanzania’ of 28 June–1 July 1999 held in Zanzibar. The booklets have been well-received, and should provide the impetus for the IMS to continue the production of public awareness print materials. Current titles are:


In summary therefore, the public awareness component implemented as a direct result of the development of the Marine Extension Education Division (MEED) has been
successful, and should continue as a sustainable component of the future activities of the IMS.

WORKSHOPS/SYMPHOSIA

It became necessary during the project to hold various local workshops to (a) determine the state of local knowledge of a particular issue, or (b) provide the opportunity for IMS and MUN personnel to participate in a variety of local/regional/sectoral workshops in order to provide information related to project initiatives in Zanzibar, and in the case of local personnel to both widen their horizons and gain recognition from a wider audience. These are listed below.


In summary, these workshops and presentations, in conjunction with the public awareness initiatives previously specified, have enabled the project to make an important contribution to non-formal and formal education in Zanzibar beyond that specified in the original outputs.

LESSONS LEARNED

Project personnel have learned various other lessons from the project, including:

1. Projects evolve as local needs change. Thus, flexibility must be possible in order that the new needs can be met whilst continuing to work within the general framework of the project.

2. Many external factors can impinge upon the successful on-time completion of a project. Often, little can be done to redress these influences, especially if they are a direct result of prevailing socioeconomic conditions.

3. Projects depend to a large extent for their success on interpersonal relationships developed.

4. Whilst the project parameters initially established might have seemed reasonable at that time, there is probably a tendency to overestimate what can be done with the time and resources available.

SUMMARY

Project activities ended in July 1999 following involvement of some MUN personnel in a symposium 'Conference on Advances in Marine Sciences in Tanzania, 28 June–1 July 1999'. The symposium was largely funded by the University of Dar es Salaam and the Swedish International Development Agency (Sida). Activities undertaken and evolving from the presence of Sida and CIDA projects (the one described here) at the IMS were considered, and suggestions made for future general initiatives. The project will formally end at the completion of the 1999–2000 fiscal year.

This project has made a valuable contribution to building the marine-related capacity of the UDSM/IMS, despite activities taking longer than expected. It has also been
necessary to revise original project objectives and outputs on an ongoing basis to take account of the evolving needs of IMS, and the nature of activities carried out under the Sida project. Nevertheless, the project has been able to make what is hoped to be a sustainable contribution to the operations of both the IMS and the parent University of Dar es Salaam in their attempts to better address marine issues in the country. Most significant has been the development and operation of a public awareness video and print capability by the establishment of a new thrust in the hitherto totally scientific activities of the IMS, namely the Marine Extension Education Division (MEED) and its media unit. The Canadian private sector has largely been responsible for this, and has shown a commendable degree of concern for the success of its involvement. Many benefits have also accrued to Canada. Memorial University of Newfoundland faculty, the Canadian private sector, and a CIDA Youth International Intern placed at IMS as an adjunct to the project, were further ‘internationalised’ by their exposure to the environmental and development issues of Zanzibar and Tanzania. Of special importance is that over the life of the project, significant and enduring personal relationships have been developed which will hopefully allow for sustainable activities. CIDA is to be thanked for its patience in allowing the project to naturally conclude, and produce beneficial outcomes.
<table>
<thead>
<tr>
<th>Video title and date of completion</th>
<th>Duration (minutes)</th>
<th>Summary of content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A boat repair in Zanzibar October 22, 1992</td>
<td>7.22</td>
<td>Interview with a boat repairer (Mr Omar) showing the repair activities</td>
</tr>
<tr>
<td>2. Utengenezaji wa boti Zanzibar (T) October 22, 1992</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>3. Sustainable development in Zanzibar July 22, 1993</td>
<td>7.22</td>
<td>Zanzibar (Unguja) Island showing some examples of development state of the town and coast</td>
</tr>
<tr>
<td>4. Maendeleo ya jamii ya Zanzibar (T) July 13, 1993</td>
<td>7.22</td>
<td></td>
</tr>
<tr>
<td>5. A resource for all generations August 3, 1993</td>
<td>15.42</td>
<td>Mangroves and their uses. Importance of sustainable use of mangroves</td>
</tr>
<tr>
<td>6. Resources for all generations July 4, 1993</td>
<td>8.34</td>
<td></td>
</tr>
<tr>
<td>7. Raslimali ya vizazi vyote (T) July 20, 1993</td>
<td>15.11</td>
<td></td>
</tr>
<tr>
<td>9. Maendeleo ndio kukua: Miaka 30 ya Mapinduzi ya Zanzibar January 25, 1994</td>
<td>35.00</td>
<td>Thirty years of the Zanzibar Revolution</td>
</tr>
<tr>
<td>10. Community in transition: The impact of seaweed farming on the women of Paje, Zanzibar, June 1, 1994</td>
<td>18.00</td>
<td>Benefits of seaweed farming and how it has changed the lives of the people</td>
</tr>
<tr>
<td>11. Jamii katika mpito (Matokeo ya kilimo cha mwani Paje, Zanzibar) (T) October 23, 1998</td>
<td>18.00</td>
<td></td>
</tr>
<tr>
<td>12. Pemba's sunken treasure (the future of Misali Island) September 5, 1994</td>
<td>29.17</td>
<td>The beauty and resources of the Island and the importance of conserving them</td>
</tr>
<tr>
<td>13. Hazina iliojificha (hatima ya kisiwa cha Misali) (T) September 5, 1994</td>
<td>29.29</td>
<td></td>
</tr>
<tr>
<td>15. Mapambano baridi (wanawake katika uvuvi Zanzibar) (T) March 10, 1995</td>
<td>19.34</td>
<td></td>
</tr>
<tr>
<td>16. University of Dar es Salaam (Silver Jubilee) July 12, 1995</td>
<td>155.00</td>
<td>Activities of the University and achievements</td>
</tr>
</tbody>
</table>

T, Kiswahili translation of preceding title.

*Continued next page*
Annex 1. Continued

<table>
<thead>
<tr>
<th>Video title and date of completion</th>
<th>Duration (minutes)</th>
<th>Summary of content</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Simple field activities in environmental education March 5, 1996</td>
<td>15.15</td>
<td>A play. Teachers demonstrating how students could conduct field activities</td>
</tr>
<tr>
<td>18. Purse Seine Fishery of Zanzibar August 29, 1996</td>
<td>20.33</td>
<td>Fishing with purse seine, some interviews with government officials and fishermen</td>
</tr>
<tr>
<td>19. Mangroves planting for our future April 1, 1997</td>
<td>5.58</td>
<td>Demonstration of mangrove replantation process</td>
</tr>
<tr>
<td>20. The threat to our beaches April 5, 1997</td>
<td>4.31</td>
<td>Effects of beach erosion</td>
</tr>
<tr>
<td>21. Application of scientific knowledge in marine and coastal management June 21, 1997</td>
<td>9.50</td>
<td>The first scientific conference and general assembly, Mombasa, Kenya</td>
</tr>
<tr>
<td>22. Garden of the sea (coral reef) August 4, 1997</td>
<td>22.51</td>
<td>Coral reefs, what they are, importance and conservation. To mark the Year of the Reef 1997</td>
</tr>
<tr>
<td>24. Zanzibar—Paradise in the Sun Island)</td>
<td>9.52</td>
<td>The beauty of Zanzibar (Unguja September 9, 1997</td>
</tr>
<tr>
<td>25. The Postgraduate Course in Tropical Coastal Ecology Management and Conservation September 17, 1997</td>
<td>12.18</td>
<td>Contents of a postgraduate course conducted in Mombasa, Kenya. Different activities done by the students</td>
</tr>
<tr>
<td>26. ANUC 1997 Part one at Sheraton Hotel Dar es Salaam January 2, 1998</td>
<td>258.00</td>
<td>African-Norwegian Universities conference</td>
</tr>
<tr>
<td>27. Pre ANUC visit to Zanzibar (the Spice Island) January 15, 1998</td>
<td>30.04</td>
<td>ANUC members visiting historical places in Zanzibar</td>
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<tr>
<td>28. Beach erosion is everyone’s concern (you too can make a difference) April 21, 1998</td>
<td>8.31</td>
<td>Beach erosion, types, causes, effects and mitigation options</td>
</tr>
<tr>
<td>29. The impacts of sea level rise on the coastal area of Unguja Island Zanzibar June 3, 1998</td>
<td>10.36</td>
<td>The aerial view showing that most tourist beach hotels are situated on the East Coast of the Island and are threatened by a sea level rise of 1.0 metres</td>
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<tr>
<td>30. The impacts of sea level rise on the coastal area of Dar es Salaam June 3, 1998</td>
<td>32.14</td>
<td>The aerial view showing that most tourist beach hotels are threatened by a sea level rise of 10 metres</td>
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Annex 1. Continued

<table>
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<tr>
<th>Video title and date of completion</th>
<th>Duration (minutes)</th>
<th>Summary of content</th>
</tr>
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<tr>
<td>31. The impacts of sea level rise on the coastal area of Dar es Salaam June 10, 1998</td>
<td>32.14</td>
<td></td>
</tr>
<tr>
<td>32. Babu Bahari (coastal life and environment) September 9, 1998</td>
<td>21.21</td>
<td>A drama showing students learning about the marine environment. A student dreams of meeting an old man who tells him about the marine environment</td>
</tr>
<tr>
<td>33. Babu Bahari (maisha na mazingira ya mwambao)(T) September 14, 1998</td>
<td>21.21</td>
<td></td>
</tr>
<tr>
<td>34. Fish mortality (in the Mahonda-Makoba drainage basin) October 18, 1998</td>
<td>09.58</td>
<td>Possible causes of fish mortality in the area, such as possible impact of sugar factory and rice fields, are discussed</td>
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*Swahili narration with English subtitles.
T, Kiswahili translation of preceding title.

Annex 2. List of IMS staff who had been to Canada through IOC and ICOD before the MUN project

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Sponsor</th>
<th>Place</th>
<th>Activity</th>
<th>Qualification</th>
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<tbody>
<tr>
<td>Shunula, J.P.</td>
<td>1985</td>
<td>IOI</td>
<td>Dalhousie</td>
<td>Marine Affairs</td>
<td>PGD</td>
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<tr>
<td>Mohammed, S.</td>
<td>1987</td>
<td>IOI</td>
<td>Dalhousie</td>
<td>Marine Affairs</td>
<td>PGD</td>
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<td>Francis, J.</td>
<td>1988/89</td>
<td>ICOD</td>
<td>Dalhousie</td>
<td>Marine Affairs</td>
<td>PGD</td>
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<td>Shaghude, Y.</td>
<td>1991</td>
<td>ICOD</td>
<td>Dalhousie</td>
<td>Marine Affairs</td>
<td>PGD</td>
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<td>Ngusaru, A.</td>
<td>1989/92</td>
<td>ICOD</td>
<td>Dalhousie</td>
<td>Physical Oceanography</td>
<td>MSc</td>
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<tr>
<td>Kyewalyanga, M.</td>
<td>1989/92</td>
<td>ICOD</td>
<td>Dalhousie</td>
<td>Oceanography</td>
<td>MSc</td>
</tr>
</tbody>
</table>
Reflections on the history of marine sciences development in Tanzania and some ideas on future challenges

Ian Bryceson

Noragric, Agricultural University of Norway, 1432 Ås, Norway

The period prior to the establishment of the Institute of Marine Sciences (IMS) of the University of Dar es Salaam in Zanzibar in 1979 and the first two years of IMS’s operation were examined in a 1982 paper entitled ‘A critical assessment of the development of marine sciences in Tanzania’ by the late Professor James Mainoya and the late Dr Boniface Mwaiseje together with the author of this paper. The present paper attempts to briefly re-examine the above assessment and to review further developments in the light of two decades of IMS’s existence.

The IMS was the first part of the University of Dar es Salaam to be sited in Zanzibar, utilising the abandoned facilities of the defunct East African Marine Fisheries Research Organisation (EAMFRO). After a rather slow start due to various difficulties during its first decade, the IMS developed impressively during the 1990s, particularly under the leadership of Dr Magnus Ngoile and Dr Julius Francis. The priorities of IMS have included training of personnel, research, offering advice and services to government bodies, influencing policies, raising public awareness, providing services to the private sector and fostering institutional cooperation in the eastern African and western Indian Ocean region and with international institutions.

The achievements of IMS include the building up of a staff of marine scientists with about twelve PhDs and several with MScs currently working towards their doctorates. In addition, many other Tanzanian and international students have done their Masters and Doctoral degrees based fully or partially at IMS. The Institute has liaised continuously with the Tanzanian Union and Zanzibar governments on matters concerning marine and coastal resources and issues. IMS has also cooperated closely with other departments at the University of Dar es Salaam including assisting in teaching and supervision, and many other institutions and organisations, both national and international.

Research programmes have been developed in the fields of (i) living resources and ecology, (ii) chemical and environmental marine sciences, (iii) physical and applied marine sciences, and (iv) marine affairs. The original bias has been towards natural and technical sciences, but increasing attention is being paid to social sciences too. IMS’s library has built up an admirable collection, and offers good services.

International collaboration has been wide, especially with neighbouring countries in the western Indian Ocean and eastern African region, but also with distant institutions in Sweden, Canada, USA, Holland and Norway.
In fairness, it must be stated that the facilities for offices and laboratories are extremely cramped and meagre. It is really a pity that IMS has not been afforded the opportunity to develop new and more spacious facilities in spite of the fact that the University acquired funds for this purpose many years ago. But IMS's achievements in spite of these inadequate facilities are all the more impressive. Let us just hope that this problem will be solved soon.

The location of the Western Indian Ocean Marine Scientists' Association (WIOMSA) in Zanzibar is a testimony to the recognition afforded to IMS by other marine scientists in the region. IMS has indeed played a leading role in the region, consistently supporting and inspiring other institutions in neighbouring countries. The IMS played a crucial catalytic role in the processes of regional cooperation in marine sciences and management, particularly towards the organising of the 'Workshop and Policy Conference on Integrated Coastal Zone Management in Eastern Africa Including the Island States' in Arusha in 1993 which resulted in the Arusha Resolution which has since been followed up in many ways by useful regional cooperation towards improved coastal management in many countries. This is a unique case of scientists taking an initiative that has been accepted and acted upon by governments.

Future success for IMS requires good leadership and collegial relations amongst IMS staff, accompanied by clear goals, strategies and plans which must be defined and then refined accordingly from time-to-time in a flexible process. The IMS needs solid backing from the University and other governmental bodies responsible. Dependable support by donor organisations should preferably be committed over reasonably long periods of time, and supportive relationships with marine science institutions in developed countries should be based upon mutual respect and benefit.

The areas that we mentioned in our paper in 1982, which have perhaps still not yet received the attention they deserve (although some work has surely been focused on them) include those of linking scientific knowledge with traditional knowledge of coastal fishing communities in a way that supports and empowers local communities to manage coastal resources sustainably. It is of crucial importance for scientists of the IMS to recognise and support the struggles of coastal peoples for their land and sea tenure and rights in the context of the institute's efforts towards understanding, managing, utilising and conserving marine and coastal resources.

The world is changing rapidly and new challenges continually manifest themselves, with the forces of globalisation and marginalisation putting increasing pressures on marine and coastal peoples and resources. Increased competence and capacity is required for IMS to continue to excel and meet the expectations of Tanzanian people. In certain situations, controversial issues and conflicts of interest may arise—it is of utmost importance for IMS to strive for scientific truth and to serve the broad long-term interests of the people so that marine and coastal resources are utilised wisely and sustainably for the benefit of development of society. Cases of attempts by certain interests to promote narrow short-term gains for a few persons, that may harm ecological
integrity and the interests of the broader majority of people must be opposed in a principled and correct manner.

I sincerely congratulate the Institute of Marine Sciences of the University of Dar es Salaam for their progress to date in their first 20 years, and I heartily wish them all the best in their efforts to continue to further build up their scientific competence and institutional capacity in order to meet the challenges of the years ahead.

Fig. 1. The old premises of EAMFRO, the predecessor of IMS

Fig. 2. Architect's impression of the current premises of IMS. A view from about the same position as in Fig. 1
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Preliminary results on the sediment sources, grain size distribution and percentage cover of sand-producing *Halimeda* species and associated flora in Chwaka Bay

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ABSTRACT

Preliminary results on the distribution of grain size, CaCO₃ content, thickness of unconsolidated sediments, and percentage cover of sand-producing *Halimeda* (green macroalgae) for Chwaka Bay are reported. At the end of this research work, these parameters will help to establish sources, sediment character, their lateral variation and relative contribution of *Halimeda* to the total sand budget in the Bay. The preliminary results show that sediment cover is higher in the northern part of the Bay (i.e. towards the open ocean) than in the southern part. Furthermore, field observations indicate that the granulometric character of the sediment differs between the eastern and western parts of the bay. The eastern part is characterised by medium to fine white sand, while coarser sediments with higher concentrations of *Halimeda* flakes characterise the western part. Also, the *Halimeda* species were observed to thrive well (high percentage cover) in the western part of the Bay compared to the eastern part. It was further noted that the northwestern part of the bay has higher percentage cover of *Halimeda macroloba* (over 80%) mixed with seagrasses, while the area towards the open ocean supported few seagrasses, with *Halimeda* species being rare or completely absent. Generally, it was observed that growth of *Halimeda* species in the southwest, southeast and areas towards the open ocean were patchy and appeared unhealthy. Laboratory results indicate that the composition of the sediments in Chwaka Bay is dominated by CaCO₃ which accounts for more than 90%. Relatively lower concentrations of CaCO₃ are observable near mangrove stands. This preliminary work suggests that the major source of the sediment in Chwaka Bay is *Halimeda*, but more work is required to determine other sources of sediments, and environmental conditions governing *Halimeda* and sediment distribution.
INTRODUCTION

In managing and conserving the marine ecosystem, aerial distribution and factors that may cause its degradation need to be determined. One of the factors that govern richness of the coastal ecosystems is sediment flux. It is well known that changes in sediment flux can cause catastrophic effects to the landscape and lead to the collapse of these ecosystems. For example, reduction in sediment supply to the Dar es Salaam beaches owing to sand mining in river bed and banks, is believed to have contributed to accelerated coastal erosion (Griffiths, 1987) and hence the loss of land and property, migration of the coastal communities landward, and destruction of coastal ecosystems. The lesson learnt on mainland Tanzania shows the need to understand the various factors that may lead to the disruption of the marine ecosystem.

On the east coast of Unguja Island (Zanzibar), there has been a tremendous increase in human activities such as construction of tourist hotels and residential houses. These activities have been accompanied by an increase in human settlement and thus increased pressure on construction materials, fresh water (which is mainly ground water) and sources of energy. Mangrove cutting (for fuelwood and construction), limestone mining, and demand for fresh water are thus on the rise. All these activities may have an impact on the sediment budget, land subsidence, zonation and flora distribution or density in the area as more land is exposed to erosion.

One of the areas on the east coast of Zanzibar where coastal communities are putting pressure on the coastal resources is the Chwaka Bay. The bay, of approximately 50km² in area, is one of the largest bays in Zanzibar and is a major economic centre as it is rich in fisheries resources, mangrove trees, and is ideal for seaweed farming. But this richness may disappear if the adverse effects of recent developments are not checked. Furthermore, despite the above-mentioned risks of altering sediment flux to the coastal waters, there is lack of quantitative information on sediment budget in most of the areas surrounding the Island including Chwaka Bay. Although the beaches of Chwaka Bay are experiencing erosion, it is not known whether the sediments eroded from these beaches and other inland areas, due to natural and anthropogenic causes, are transported along the shore or offshore. The impact of this sediment transport on the biota is also unknown. Moreover, the sediment distribution, type and their characteristics as well as its sources are not known. It is common belief that sand supply to the beaches and nearshore areas is derived largely from the surrounding land masses. But in some places autochthonous production may contribute greatly to the sand budget. Although it appears that the bay supports CaCO₃ producing Halimeda, their role in contributing to the total sand budget is not known. Thus, the present work presents the results of an initial field and laboratory survey on sediment sources and their characteristics in terms of grain size distribution, sediment thickness and percentage cover of some flora that are likely to be producers of sand in Chwaka Bay.
STUDY AREA

Chwaka Bay, which is a shallow and partly sheltered lagoon, is located 22 km east of Zanzibar town (Figure 1). Several villages, namely Chwaka, Marumbi, Michamvi, Urowa and Charawe, surround the bay. Also, a thick mangrove forest surrounds a large part of the bay, and on several occasions the forest is dissected by a number of creeks that enter the bay. Previous investigators have indicated that the bottom of the bay is covered by a mixture of seagrasses and algal assemblages (Wolanski, 1989; Mohammed and Johnstone, 1995), though their distribution pattern and species compositions are not well known. The bay experiences a semi-diurnal tide, with a mean spring tidal range of 3.2 m (Cederlöf et al., 1995), and is fringed by a coral reef at the entrance extending over most of Zanzibar coast. At lowest spring tide a large part of the bay (more than 60%) is exposed, and because of this fluctuation, the tides regulate the activities of communities around the bay on short cycle basis (Tobisson et al., 1998).

MATERIALS AND METHODS

To obtain initial results on regional coverage of biota and sediment characteristics in Chwaka Bay, 54 locations were visited (Figure 1). At each location, a sediment sample for grain size analysis, and determination of CaCO₃ was collected using a Van Veen
grab sampler. Sediment colour and grain size were visually noted. Also at each sampling site, the biota cover was quantified using a 1 x 1 m² quadrat divided into 100 equal, small squares, thrown at random. The percentage cover of each individual life form within the quadrat was determined by counting the number of squares occupied — each square representing 1%. Distributions of fauna and flora in the vicinity of the quadrat were categorised by visual observation and each category assigned as 'patchy' or 'aggregated'.

Subsamples for determination of CaCO₃ were dried at a temperature of 60°C, ground to fine powder, weighed and acidified with 2M HCl. The difference in weight between the dried acid residue and initial weight of powder was taken to be CaCO₃ content. The CaCO₃ contents are presented in percentages and reproducibility is within 2%. Sediment thickness was estimated by pushing a 5-m-long iron bar into the sediments until it reached the basement especially in waters that were less than 3 metres deep.

RESULTS

Both laboratory and field observations show that the eastern part of Chwaka Bay is characterised by medium to fine white sand, while coarse sand rich in Halimeda flakes is confined to the central, western and northwestern parts of the bay (Figure 2). Fine sediments were also observed in the southern part of the bay towards the mangrove forests. Areas that were observed to have coarse sediments had the highest percentage

Figure 2. Mean grain size distribution in the Chwaka Bay in phi-values. Fine grain size particles are found in the eastern part of the bay

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Figure 3. Percentage cover of *Halimed* species in the Chwaka Bay

Figure 4. Distribution of seagrasses in Chwaka Bay
cover of *Halimeda*, with *H. macroloba* being dominant in the northwestern part (Figure 3). The distribution and percentage cover of seagrasses were also observed to follow the same distribution pattern as the *Halimeda* species except that most of them were concentrated in the middle of the Bay and near the shore towards the north (Figure 4). Some stands of seagrasses were found in the southwest, north and northeastern parts, although they looked unhealthy. Other species of macroalgae were confined to few locations with patchy distribution compared to the *Halimeda* and seagrasses.

The greatest sediment thickness was observed towards the open ocean (Figure 5). Most of the southern part of the bay, including the creeks, had rocky bottoms with a thin layer (generally less than 10 cm) of fine to medium-grained sand. With regard to CaCO$_3$, the content is generally higher than 90%, and is low in the southern part towards the mangrove forest (Figure 6).

![Map of CHWAKA BAY](image)

*Figure 5. Lateral variation in sediment thickness (m) to the bedrock in CHWAKA BAY*

**DISCUSSION**

Field observations suggest that the eastern part of CHWAKA BAY has finer material relative to the western part. Using global trends (e.g. Dyer, 1984; Nyandwi, 1995; Muzuka and Shaghude, 2000), the eastern part would correspond to a low energy environment while the western part would be under the influence of a high energy environment. However, the eastern side has been reported to have stronger tidal currents relative to the western part of the bay (Wolanski, 1989; Mwaipopo, 1998), and thus excluding this possibility. The
Figure 6. Concentrations of CaCO$_3$ in surficial sediments recently deposited in the Chwaka Bay occurrence of very coarse sediments in the western part is likely to be related to the source of the sand in the Chwaka Bay. This is because of high correspondence between areas with coarse grain size and areas with the highest percentage cover of *Halimeda*. Finer particles in the eastern part could be a result of systematic grinding of the *Halimeda* flakes derived from the western part during transport. However, the transport path is not well known and more detailed work is required to address this issue.

A biogenic source inferred above is further supported by the concentration of CaCO$_3$ which is generally higher than 90% and almost the same between the eastern and western parts of the bay (Figure 6). Since the area lacks major rivers that can contribute a significant quantity of siliciclastic material, its high content of CaCO$_3$ may suggest biogenic origin of sand in the Bay, probably derived from *Halimeda* and other carbonate-secreting organisms. However, relative contribution of other sources such as corals and foraminifera, need to be determined prior to concluding that *Halimeda* is a major source of sand in the area.

The thickness of sediment cover in Chwaka Bay varies considerably, with the thinnest layers being observable in the southern part of the bay. The unconsolidated sediments overlie the older eroded cliffed-coral platform. The platform most likely is of Pleistocene or older periods. Such distribution pattern could have resulted from erosion/deposition processes as a response to the Holocene rise in sea level, or circulation pattern in the bay. During the last glacial period, the sea level is considered to have been 130m below its present level (Fairbank, 1989). Since then, fast rise in sea level particularly during the
Holocene has been recorded (Fairbank, 1989). A global sea level rise means that land retreat has been significant. As the sea level rose, erosion took place, as it is currently evidenced on the east coast of Zanzibar where cliff under-cut is a common phenomenon. Eroded material could have been transported to deeper parts of the Chwaka Bay by strong ebb currents. The ebb currents are strong and are capable of transporting large quantity of sediments, thus removing sediments in recently eroded areas. Since tidal channels have thinner sediment cover, while the flank has the highest sediment cover, most likely the observed distribution of sediment thickness can be attributed to the circulation pattern in the bay and not to the Holocene rise in sea level.

Although patchy distribution and percentage cover of biota is a common global observation (e.g. Sousa, 1984; Kirkman, 1990; Ndaro and O’lafsson, 1998), the existence of high percentage cover of Halimeda in the western and northwestern parts of the bay relative to the eastern part requires further detailed studies. As previous workers pointed out, probably the observed biota distribution may be related to the differences in physico-chemical factors between eastern and western parts (Ndaro and O’lafsson, 1998). On the eastern part, lack of high percentage cover could probably be related to large exposed area during low tide and higher flux of finer particles associated with strong ebb and flood currents, which may hinder growth of Halimeda relative to the western part. Thus, studies to better understand bottom topography, nutrient concentration, and current flow pattern during flood and ebb periods, and concentration of particulate material in the bay are required.

CONCLUSION

Initial findings suggest that there is a systematic change in the grain size distribution across the Chwaka Bay with coarser material being deposited in the western and finer particles in the eastern parts. Areas with coarsest sediments are also rich in Halimeda flakes and are associated with high percentage cover of sand-producing Halimeda, suggesting a biogenic source of sediments in the Chwaka Bay. Although particulate material deposited in the eastern part of the bay may be derived from the western part, transport path is not known and this calls for a more detailed work to establish current patterns and the strength/concentration of particulate material in the water column. There is no major difference in the contents of CaCO$_3$ between the two areas, an indication of similar source.

Sediment thickness is high in the northwestern part of the bay probably due to Holocene rise in sea level or circulation pattern. More work is required to find out if sediments are transported northward before being deflected back by flood currents.
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Sources of organic matter in the Msasani Bay and Dar es Salaam Harbour

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ABSTRACT

The stable isotope compositions of organic carbon and nitrogen, contents of organic carbon, nitrogen and calcium carbonate (CaCO$_3$), and C/N ratios for surficial (grab samples) are used to document variations in the sources of organic matter in the Msasani Bay and the Dar es Salaam harbour. Also, grab samples collected within the study area are used to establish a dispersion pattern in the area. The stable isotope compositions of organic carbon for sediments collected from the Msasani Bay and the Dar es Salaam harbour range from -21.3‰ to -14.0‰ and average -17.3±1.3‰. Sediments collected from the Dar es Salaam harbour and off the Msimbazi River are characterised by low stable isotope values of organic carbon, high C/N ratios, and high contents of organic carbon and nitrogen relative to those collected outside the harbour and the Msasani Bay. Low stable isotope values in the harbour and off Msimbazi River suggest a significant input of terrestrial material to the area. In the Msasani Bay, there is a general enrichment in $^{13}$C by about 1‰ in nearshore sediments when compared to offshore areas. This trend is also associated with a shore-offshore increase in CaCO$_3$. An enrichment in $^{13}$C in nearshore waters relative to offshore areas suggests that the contribution of C$_3$ plants is minimal and particulate material is largely derived from seagrasses and seaweeds that thrive well in the area. An increase in CaCO$_3$ concentration with distance offshore indicates a decrease in the dilution by siliciclastic material, and little exchange of particulate material between offshore and nearshore areas. Nitrogen stable isotope compositions in the Msasani Bay and the Dar es Salaam harbour show no clear trend.

INTRODUCTION

The coastal waters of Tanzania, like other coastal areas in the world, receive large quantities of organic materials from different sources that include municipal discharge, autochthonous production, hinterlands and from erosion of former deposits located along the coast. The organic material introduced in the ocean causes high concentration
of nutrients which are normally associated with elevated levels of primary productivity. This implies that if input of particulate material to the marine environment is not monitored, disastrous environmental degradation may occur. Therefore, it is important to identify potential sources in order to halt unwanted inputs. In Tanzania, few studies have been conducted to delineate various sources of organic matter in the coastal areas, particularly off major cities and towns, where input of allochthonous material is likely to be high owing to high population. One of the notable studies in the country along these lines is that of Muzuka (1999a) which reported the stable isotope compositions of organic carbon and nitrogen for a few marine samples as well as coastal flora. Another work is that of Muzuka (1999b), which was conducted off Zanzibar town using stable isotope compositions of organic carbon and nitrogen. In the latter study, it was shown that particulate material originating from municipal discharge is not transported far offshore. A trend of decrease in the stable isotope compositions of organic carbon and nitrogen with increasing distance offshore has also been noted elsewhere in the world (e.g. Peters et al., 1978; Macko, 1983; Lucotte et al., 1991; Holmes et al., 1996). Furthermore, it has been shown that this trend is not confined to the marine environment, but also occurs in the lacustrine environment (Tenzer et al., 1997).

The quantity of organic material preserved in the marine sediments may sometimes be an indicator of the level of pollution in coastal waters. For example, in heavily polluted coastal marine zones, the contents of organic carbon and nitrogen have been observed to be higher than in areas experiencing higher primary productivity such as Peru and Oman upwelling areas (Romankevich, 1984). The major problem in assessing the level of pollution caused by human input of organic material is identification and estimation of the relative contribution of each source. A method that has been widely used is determination of the stable isotope compositions of organic carbon and nitrogen in the marine environment (Tan and Strain, 1983, 1979a,b; Macko, 1983; Gearing, 1988; Muzuka, 1999b). These isotopes have been used under the assumption that the end member values for each source are distinct. For example, the stable isotope compositions of seagrasses and macroalgae have been found to range from -20‰ to -12‰ (Behrens and Frishman, 1971; Fry and Sherr, 1984; Stephenson et al., 1984; Gearing, 1988; Ostrom and Macko, 1992), while that of terrestrial C₃ plants average -26‰ (Degens, 1969; Deines, 1980; Fry and Sherr, 1984). With these distinct isotopic compositions, the relative contributions of each source in coastal areas can be arrived at quite easily using mass balance (mixing) equation. However in an environment like Tanzania, where a large part of the country is covered by savanna vegetation, the contribution of C₄ plants that have a mean value of -12‰ may not be easily distinguished from that of macroalgae and seagrasses. The use of other parameters such as the C/N ratios in combination with the stable isotope compositions of organic carbon and nitrogen may be an additional tool that may help in delineating terrestrial and marine sources. Application of these multiple parameters has been successfully applied globally,
particularly the stable isotopes (Peters et al., 1978; Sweeney et al., 1980; Macko, 1983; Wada et al., 1987; Thornton and McManus, 1994).

Particulate materials derived from the continent after entering the marine environment is dispersed according to existing tidal and other coast currents, including rip and longshore currents. For example, a northwards decrease in the mean grain size that was associated with improvement in sorting in the tidal flat in the Msasani Bay was interpreted as an indication of a preferential northward transport of sediments along this area (Muzuka and Shaghude, 2000). Apart from information on a general transport pattern of beach material along the Msasani beach (Muzuka and Shaghude, 2000) knowledge on the dispersion pattern of particulate material within the bay and the Dar es Salaam harbour is lacking. Even information on the current pattern in the area is poorly known. Only recently has there emerged new information on current flow patterns in the Msasani Bay north of Bongoyo Island (Lwiza, 1987; Dubi and Nyandwi, 1999). Generally, the ebb current which is responsible for transporting particulate material offshore is northwards (Lwiza, 1987; Dubi and Nyandwi, 1999).

Nonetheless, information on the sources, quantity and quality of organic matter in Tanzanian nearshore waters is insufficient. Moreover, the dispersion pattern of allochthonous particulate material is lacking. Even baseline information on the stable isotope compositions of organic carbon and nitrogen for both sedimentary material and flora is insufficient. Therefore, the present work was intended to: (1) provide some data on the stable isotope compositions of organic carbon and nitrogen, and contents of organic carbon, nitrogen and calcium carbonate; (2) document various sources of organic material in the study area and estimate their relative contribution, and (3) establish dispersion patterns of particulate organic matter in the Msasani Bay and the Dar es Salaam harbour.

**STUDY AREA DESCRIPTION**

The area under study extends from the Dar es Salaam harbour to Kunduchi and from the shoreline to offshore areas beyond the islets (Figure 1). The area has two rainy seasons, i.e. November–December, and March–May, with the heaviest rainfall occurring between March and May. Large loads of allochthonous material are deposited in the ocean during these rain seasons, and major conduits are rivers. Along the Tanzanian coast, the major rivers capable of transporting large quantity of particulate material to the sea are the Rufiji, Ruvu and Wami rivers. However, all these rivers are significantly far away from the study area. Only seasonal streams which drain the study area, such as the Msimbazi, Kijitonyama, Mbezi, Mdumbwe, Manyema Creek, and Tegeta play a major role in depositing land-based material.

Since the study area is located in the equatorial belt on the western coast of the Indian Ocean, it is subjected annually to two types of seasonal wind patterns: the southeasterly (SE) monsoons, which are prominent between April and October, and the northwesterly (NW) monsoons which are prominent from November through March.
Figure 1. Location of sampling sites in the Msasani Bay and Dar es Salaam Harbour
The SE monsoons are generally stronger and less variable in direction than the NW monsoons. This results in a northward moving current along the coast throughout the year (Alexander, 1966; Bargman, 1970; Temple, 1970; Kaaya, 1985). Further, because of the steepness of the continental margin the currents are close inshore and are only impeded, never reversed by the NW monsoon along this section of the coast (Temple, 1970; Shamshugan, 1981). Although currents are close inshore, the major agent responsible for dispersal of particulate material is the tidal current.

Geologically, the study area and its surrounding coastal plain are studded by rock formations which range in age from Jurassic to Recent (Kent et al., 1971). The low-lying coastal areas such as river valleys and depressions are covered by Neogene non-marine sediments which are overlain by Miocene-Pliocene sediments. The Miocene-Pliocene sediments are unconsolidated, poorly sorted gravels, sands, silt and clay. These sediments are overlain by raised reef limestones, beach ridges, sand dunes, beach deposits and superficial white-buff sands of Pleistocene-Holocene age. All the islets are composed of raised Pleistocene reef limestone. Furthermore, the coastal zone is intensely dissected by NE-SW faults probably of post-Miocene age (Kent et al., 1971). These faults act as contacts between the sedimentary coastal strata and the Precambrian basement rock of the interior plateau (Alexander, 1968).

MATERIALS AND METHODS

A total of 42 sediment samples were collected from the Msasani Bay and the Dar es Salaam harbour (Figure 1) using a grab sampler. All samples were frozen immediately after returning from the field until processing, where they were dried at 60°C, and then ground to a finer powder using diamondite mortar. Aliquots for determination of residue organic carbon and nitrogen and stable isotope compositions of organic carbon and nitrogen were acidified using 1M HCl and then freeze-dried. The contents of total carbon (untreated material), residue organic carbon (treated material) and nitrogen contents were determined using C-H-N analyser that was coupled to a FINGAN-MAT mass spectrometer. Determination of stable isotope compositions of organic carbon and nitrogen were achieved using a FINGAN-MAT mass spectrometer. The \( \delta^{13}C \) and \( \delta^{15}N \) values are reported relative to PDB and atmospheric nitrogen respectively. On the basis of replicate analysis of samples, the reproducibility for the stable isotopes of organic carbon and nitrogen is within ±0.2‰ while that of contents of organic carbon and nitrogen is ±0.01%. Reproducibility for the \( \text{CaCO}_3 \) is within ±1%.

RESULTS

The stable isotope compositions of sedimentary organic matter in the Dar es Salaam harbour and Msasani Bay range from -21.3‰ to -14.0‰ and average -17.3±1.7‰ for \( \delta^{13}C \), while the \( \delta^{15}N \) values range from 1.7‰ to 8.2‰ and average 5.3±1.3‰. In the Dar es Salaam harbour, the \( \delta^{13}C \) values show a general increase with increasing distance from
the shoreline (Figure 2). Contrary to the $\delta^{13}$C distribution pattern, the $\delta^{15}$N values decrease with distance in the Dar es Salaam harbour area (Figure 3). Within the Msasani Bay, the $\delta^{13}$C values show a general northward decrease (Figure 2), while that of $\delta^{15}$N show a

Figure 2. Lateral variations in the stable isotope compositions of organic carbon (%) in the Msasani Bay and Dar es Salaam Harbour
systematic increase from the shoreline (Figure 3). Outside the Msasani Bay, i.e. east of the Bongoyo-Mbudya Island system, the $\delta^{13}C$ and $\delta^{15}N$ values decrease with increasing distance offshore (Figures 2 and 3).

Figure 3. Distribution of nitrogen stable isotope values (δ-notation, ‰) in coastal waters off the city of Dar es Salaam and within the Msasani Bay
Figure 4. Concentration of organic carbon (%) in recently deposited sediments in the Msasani Bay and Dar es Salaam Harbour
Figure 5. Variation in the content of nitrogen (%) for organic matter preserved in the Msasani Bay and Dar es Salaam Harbour sediments.
Figure 6. C/N ratio values for recently deposited sediments in the Msasani Bay and Dar es Salaam Harbour
Figure 7. A map showing distribution of percentage content of CaCO$_3$ in the sediments recovered from the Msasani Bay and Dar es Salaam Harbours.
The concentration of CaCO$_3$ in the Msasani Bay and the Dar es Salaam harbour, which range from 0 to 100% and average 50±34%, increases offshore, with the lowest concentration being observable in the Dar es Salaam harbour and in nearshore areas in the Msasani Bay (Figure 4). The contents of organic carbon and nitrogen are generally low, although slightly higher values are observable within the Dar es Salaam harbour (Figures 5 and 6). Sediments deposited within the harbour have higher values of C/N ratios relative to other areas (Figure 7). In terms of absolute values, the contents of organic carbon range from 0.05 to 2.8% and average 0.76±0.8%, while those of nitrogen range from 0.01 to 0.27% with a mean value of 0.08±0.08%.

DISCUSSION

A general increase with distance offshore in the stable isotope compositions of organic carbon and nitrogen like the one observed in the Dar es Salaam harbour has been observed in the Gulf of St Lawrence (Tan and Strain, 1979a,b, 1983; Gearing et al., 1984; Gearing, 1988; Lucotte et al., 1991), in the Gulf of Mexico (Hedges and Parker, 1976; Macko, 1983), in the Congo estuary (Holmes et al., 1996), and in the Newfoundland fjords (Ostrom and Macko, 1992). All workers in these areas have suggested that this trend was a result of a decrease in the influence of terrestrial material with increasing distance offshore. A trend observed in this study can also be attributed to a decrease in the influence of terrestrial material offshore. Since the study area does not exceed 15km from the shoreline, an offshore increase in the stable isotope compositions of organic carbon and nitrogen suggest that terrestrial and municipal materials are not transported far offshore. High proportion of terrestrial material in the harbour is further supported by high C/N ratios which are of terrestrial nature (Meyers, 1994). A relatively high concentration of particulate organic carbon and nitrogen in the Dar es Salaam harbour that is associated with high C/N ratios may further suggest that the Dar es Salaam harbour is a sink of anthropogenic material. This implies that material introduced into the harbour is not completely flushed out. Lack of removal of allochthonous material in the harbour is further supported by existence of silt-clayey sediments that were observed during sampling in the area.

Outside the Dar es Salaam harbour, the proportion of terrestrial material is low. However, if the isotopic compositions of terrestrial material entering the harbour is enriched in $^{13}$C owing to mixing of terrestrial C$_3$ and C$_4$ plants such that the resulting mixture has a value of about -20%, then the proportion of allochthonous material could be higher than predicted above. Such an end member value could easily be achieved if there is mixing of equal proportions between C$_3$ and C$_4$ organic material.

The nitrogen stable isotope compositions of coastal flora has been observed to be higher than 5% (Muzuka, 1999b). Furthermore, the nitrogen isotope compositions for seagrasses has been observed to average 2‰ (Gearing, 1988). Therefore a decrease in the nitrogen isotope composition could be a result of mixing between isotopically heavy
allochthonous material with that of seagrasses and macroalgae which were abundant during sampling.

As pointed out above, the isotope values of organic carbon in the Msasani Bay increase northwards. Since the tidal and wind generated currents flow northward regardless of the season (Lwiza, 1987; Dubi and Nyandwi, 1999), this trend could be related to the current pattern in the study area. A northward flow of currents means that the particulate material within the bay and sediments along the beach are transported northward. The result of this work further supports earlier observations of a northward decrease in the mean grain size that was associated with an improvement in sediment sorting along the Msasani beach (Muzuka and Shaghude, 2000).

The stable isotope compositions of soil nitrate is low relative to the oceanic nitrate (Cline and Kaplan, 1975; Shearer et al., 1978; Selles et al., 1986; Liu and Kaplan, 1989). Because of this, oceanic particulate material is generally enriched in $^{15}$N when compared to the terrestrial material. Compilation of global $^{15}$N data has indicated that the stable isotope compositions for terrestrial material averages 2‰, while that of oceanic particulate material averages 7‰ (Létolle, 1980; Macko, 1981; Kaplan, 1983). Such isotopic difference between terrestrial and marine particulate material has led to a worldwide application of this parameter in delineating sources and estimating their relative contribution (Peters et al., 1978; Kaplan, 1983; Macko, 1983). Assuming that the general global trend is applicable to the Tanzanian coastal waters, a general increase in the stable isotope compositions of nitrogen with increasing distance offshore may be an indication of decrease in the influence of the terrestrial material offshore. In terms of dispersion pattern, it implies that incidences of sediment transport by rip currents, which is one of the major processes responsible for sediment transport offshore (Kenneth, 1982), is minimal. A decrease in the offshore transport of allochthonous material is further supported by the concentration of CaCO$_3$, which increase with increasing distance offshore (Figure 4). A decrease in the contents of CaCO$_3$ suggests that dilution by siliciclastic material decreases offshore, an observation which is in close agreement with the stable isotope compositions of organic carbon and nitrogen in the Dar es Salaam harbour.

The stable isotope compositions of organic carbon and nitrogen east of the Bongoyo-Mbudya island system decreases with increasing distance offshore (Figures 2 and 3) with $\delta^{13}$C and $\delta^{15}$N values less than -16‰ and 6‰ respectively. As pointed out above, particulate material within the Msasani Bay are not transported directly towards the open ocean probably due to fringing reefs that are located just east of the Bongoyo-Mbudya islands. A slight enrichment in the stable isotope just east of the two islands, where extensive coral reef platforms are found, may be an indication of high utilisation of available nutrients and dissolved CO$_2$, with lower decreasing rates of nutrient utilisation as one goes away from the coral platform. Both field observations and laboratory experiments have indicated that organic matter formed in areas with high nutrient utilisation are enriched in $^{13}$C and $^{15}$N (Montoya et al., 1992; Altabet and Francois, 1994a,b; Montoya, 1994). Isotopic enrichment occurs in areas with higher nutrient utilisation owing
to the fact that organisms tend to use all available nutrients regardless of their isotopic compositions (Montoya, 1994). In contrast, when the nutrients are abundant relative to the demand, organisms tend to utilise light isotopes as they have weaker bonds (Altabet and Francois, 1994a, b; Montoya, 1994). It has been reported that nutrient concentrations in world coral reefs is low (Bell, 1991; Björk et al., 1995), and most probably the coral reefs in the study area are no exception. With such low concentrations of nutrients, it is likely that the utilisation of available nutrients is optimum.

CONCLUSION

This work shows that material derived from the surrounding land mass is not transported far from the shoreline and the Dar es Salaam harbour acts as a sink of particulate material as residence time of the water is high. In the Msasani Bay, particulate materials are transported northwards. Apart from the terrestrial sources, seagrasses and macroalgae contribute a significant quantity of organic matter to the total sedimentary organic matter preserved in the study area.

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Mobility and immobility of mid-ocean ridges and their implications to mantle dynamics

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ABSTRACT

In the past two decades, the mobility of mid-ocean ridges relative to the mantle (absolute migration) has been correlated with major observable features, such as spreading asymmetry and asymmetry in the abundance of seamounts. The mobility of mid-ocean ridges is also thought to be an important factor that influences the diversity of ridge-crest basalts. However, this mobility has not yet been defined and mapped. The absolute migration of global mid-ocean ridges since 85 Ma has been computed and mapped. Global mid-ocean ridges have migrated extensively at varying velocities during that period. Presently, the fast-migrating ridges are the Pacific-Antarctic, Central Indian Ridge, Southeast Indian Ridge, Juan de Fuca, Pacific-Nazca, Antarctic-Nazca, and the Australia-Antarctic ridges, migrating at velocities of between 3.3 and 5.5 cm/yr. The slow-migrating ridges are the Mid-Atlantic and the Southwest Indian ridges, migrating at velocities between 0.3 and 2.0 cm/yr. Comparison of these results with mantle tomography results show that the slow-migrating ridges have deeper depth of origin than the fast-migrating ones, suggesting a correlation between the absolute migration velocity and the depth of origin of ridges. Furthermore, the Southwest Indian ridge appears to be tapping the same portion of mantle as did the Central Indian ridge. These results have important thermo-chemical implications, such as variations in the extent of melting and mineralogical composition of the mantle beneath different ridges, which may influence mantle dynamics.

INTRODUCTION

Mid-ocean ridges are important features of the earth for several reasons: in plate tectonics they are boundaries of plates and play a key role in driving them; and in geophysics they are locations along which new seafloor is created. Absolute migration of mid-ocean ridges have been correlated with major observable features of the ridges. For example Stein et al. (1977) correlated spreading asymmetry with migration rate, and Davis and Karsten (1986) explained asymmetry in seamount abundance by absolute
ridge migration. Ridge migration rate is also thought to be an important factor that influences the diversity of ridge-crest lavas and the compositional uniformity of ridge-crest basalts (Davis and Karsten, 1986). Although absolute migration of mid-ocean ridges has been linked with many features, its influence to mantle dynamics has not yet been investigated.

In this paper, therefore, the absolute migration of global mid-ocean ridges since 85 Ma is computed and its possible influence to mantle dynamics investigated.

**METHODS**

Magnetic lineations form concurrently with new seafloor on mid-ocean ridges when molten magma passively upwells into the narrow space between two diverging plates. Magnetic domains/minerals in the magma are aligned in the direction of the prevailing geomagnetic field, thus recording the age of the new seafloor. Fifteen ridge segments are selected (Figure 1), with their corresponding magnetic lineation segments on both sides. Their paleopositions since 85 Ma to Present are reconstructed by rotating identified magnetic lineations back to their former positions (Masalu and Tamaki, 1994), using the models of absolute motion of plates by Muller and Smith (1993) and Duncan and Clague (1985). The absolute migration velocities for each respective ridge are then computed.

Locations of identified magnetic lineations were obtained from a CD-ROM of digital data of locations of global magnetic lineations (Cande et al., 1989). Ages were assigned

Figure 1. Global mid-ocean ridges (shown with a thin black line). Crosses indicate ridge segments that were selected for reconstructions done in this study.
to identified magnetic lineations based on a recent geomagnetic polarity time scale for the Late Cretaceous and Cenozoic time (Cande and Kent, 1992).

The assumption in the methodology is that plates have remained rigid over the past 85 million years. This is certainly not completely correct because both inter- and intra-plate deformations are known to exist. Errors may also arise from incorrectly identified magnetic lineations. There are also inherent errors from the use of models of absolute plate motions.

RESULTS

Migration of global mid-ocean ridges
Regardless of the possibility of the errors described above, the results present a first overview of global motion of mid-ocean ridges. The results obtained indicate that global mid-ocean ridges have migrated extensively in the past 83 million years (Table 1 and Figure 2). All ridges appear to be migrating: the East Pacific Rise (EPR) appears to have rotated clockwise for about 50° since 83Ma (Figure 2i). The South Mid Atlantic Ridge (SMAR) shows small lateral migration but indicates extensive longitudinal migration toward north (Figure 2ii). Similarly, the northern EPR and the Juan de Fuca ridge segments appear to have migrated northerly at least since about 83Ma (Chron 34) to the Present (Figure 2i).

The SMAR runs between several hotspots located relatively close to it on both sides which probably played a role in limiting its lateral migration (Uyeda and Miyashiro, 1974).

Contrary to the SMAR, the Central Mid Atlantic Ridge (CMAR) between the equator and latitude 40° N, and the Northern Mid Atlantic Ridge (NMAR) north of the 40° N latitude, has been migrating northwesterly since 83Ma to Present (Figure 2ii). This suggests the existence of active deformation between the SMAR and the CMAR at least since 83Ma. The present results may offer one explanation of the origin of tectonic

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Ridge</th>
<th>Distance migrated (km)</th>
<th>Time to Present (million years)</th>
</tr>
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<tbody>
<tr>
<td>JUAN</td>
<td>Juan de Fuca</td>
<td>3900</td>
<td>83</td>
</tr>
<tr>
<td>PacAnt</td>
<td>Pacific-Antarctic</td>
<td>2400</td>
<td>73</td>
</tr>
<tr>
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<td>Pacific-Nazca</td>
<td>200</td>
<td>12</td>
</tr>
<tr>
<td>AntNaz</td>
<td>Antarctic-Nazca</td>
<td>1010</td>
<td>20</td>
</tr>
<tr>
<td>SMAR</td>
<td>South Mid-Atlantic Ridge</td>
<td>1300</td>
<td>83</td>
</tr>
<tr>
<td>CMAR</td>
<td>Central Mid-Atlantic Ridge</td>
<td>1200</td>
<td>83</td>
</tr>
<tr>
<td>NMAR</td>
<td>North Mid-Atlantic Ridge</td>
<td>1550</td>
<td>83</td>
</tr>
<tr>
<td>SEIR</td>
<td>Southeast Indian Ridge</td>
<td>3900</td>
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<td>83</td>
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<tr>
<td>SWIR</td>
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<tr>
<td>AustAntar</td>
<td>Australia-Antarctic</td>
<td>1400</td>
<td>43</td>
</tr>
</tbody>
</table>
Figure 2. Migration of mid-ocean ridges for some of the selected ridge segments. Solid thick line segments are reconstructed zero-age paleopositions of selected ridge segments at a Chron age indicated by the adjacent numbers. Text with a pointing arrow is ridge identifier as in Table 1. (i) (above) Pacific ridges (Juan de Fuca and South Pacific ridges), (ii) (top, opposite page) Atlantic ridges (SMAR, CMAR and NMAR), (iii) (bottom, opposite page) Indian Ocean ridges (CIR, SEIR, SWIR and AustAntar). Note that the CIR and SWIR (line connecting solid squares on the figure, and inset) sampled the same locality at different times.
complexity in the equatorial Atlantic region, an area characterised by a dense pattern of mostly medium to large offset fracture zones as well as a series of unusual ridges and troughs (Mueller and Smith, 1993). These investigators have also suggested that the equatorial Atlantic region recorded the migration of the plate boundary between the North and South American plates. Based mainly on evidence from fracture zone trends, it has been proposed that the boundary was located in the equatorial Atlantic for a significant time span between the Late Cretaceous and Late Tertiary (Roest, 1987; Roest and Collette, 1986) periods.

For the Indian Ocean mid-ocean ridges, the results show that paleopositions of the Central Indian Ridge (CIR) between Chron 29 and Chron 25 coincide with those of the Southwestern Indian Ridge (SWIR) between Chron 20 and Present (Figure 2iii). This implies that the SWIR may be tapping the same portion of the mantle as did the CIR between Chron 29 and 24.

**Absolute ridge migration velocities and mantle tomography**

The absolute migration velocities of all ridges investigated in this study are shown in Figure 3. The ridges divide into two groups: the slow-migrating ridge group including the CMAR, SMAR, NMAR and the SWIR ridges, and the fast migrating ridge group including all other remaining ridges. Presently, slow-migrating ridges are migrating at velocities between 0.3–2.0 cm/yr whereas fast-migrating ridges are migrating at velocities between 3.3–5.5 cm/yr.

The results were compared with seismic velocity anomalies beneath global mid-ocean. Su et al. (1992) shows that seismic velocity anomalies associated with mid-

![Figure 3. Variation of migration velocities of global mid-ocean ridges. Text identifiers as in Table 1](image-url)
ocean ridges appear as continuous features to 300km depth. For the NMAR, SMAR, Pacific-Antarctic ridge (PacAnt), SWIR, and the Carlsberg ridges, seismic velocities remain slower than normal, on average down to 400km depth, and this situation persists to 600km depth. Except for the PacAnt, the 'deep-rooted' ridges are the slow-migrating ridges (Figure 3). As for the PacAnt, though falling in the same group with fast-migrating ridges, it is the slowest ridge in the group. These results suggest the existence of a correlation between absolute migration velocities and the depth of origin of mid-ocean ridges, whereby fast-migrating ridges have shallow depth of origin and slow-migrating ones have deeper depth of origin. Intuitively, this may be explained as follows: mantle from the same vertical locality beneath a ridge have more time for passive upwelling for slow-migrating ridges and less time for fast-migrating ridges. Slow-migrating ridges allow the development of stable and deep-rooted mantle convection cells beneath them, whereas fast-migrating ones probably cause some disturbances to mantle convection cells beneath them, and thus allow only the development of shallow-rooted convection cells.

DISCUSSION

The observations that the SWIR may be tapping the same portion of the mantle as did the CIR, and the correlation between absolute migration velocity and the depth of origin of mid-ocean ridges has far-reaching thermal and chemical implications. One of the most important dynamic processes in the earth's interior is thermal convection in the mantle. Currently, two methods are used to study temperature variations in the upper mantle: the study of major-element chemistry of basalts erupted at mid-ocean ridges which is directly influenced by the temperature of the mantle beneath (e.g. Klein and Langmuir, 1987), and seismic velocity studies (e.g. Su et al., 1992).

Klein and Langmuir (1987, 1989) studied the chemical systematics of global mid-ocean ridges and proposed a model to explain the observed chemical systematics of global MORB (Mid-Ocean Ridge Basalts) by variations among different melting columns. According to their model, a hotter parcel of the mantle (from deeper depths) intersects the solidus at greater depths and produces a taller melting column, leading to greater mean pressures and extent of melting, whereas a cooler parcel of mantle (from shallow depth) intersects the solidus at shallower depths and produces a shorter melting column, leading to lower mean pressures and extent of melting. Their model can be combined directly with the results of this study whereby fast-migrating ridges correspond to ridges with cooler sources of parcels of mantle, and slow-migrating ridges correspond to ridges with hotter sources of parcels of mantle. The combined result predicts that the fast-migrating ridges (e.g. the SEIR) will have deeper water depths and their basalts will have relatively high Na$_{8.0}$ and SiO$_2$ with low Fe$_{8.0}$ and CaO/Al$_2$O$_3$, and that slow migrating ridges (e.g. the NMAR) will be shallow in water depth and their basalts would have relatively low Na$_{8.0}$ and SiO$_2$, but relatively high Fe$_{8.0}$ and CaO/Al$_2$O$_3$. Additionally,
these results suggest that the mantle beneath fast-migrating ridges has undergone smaller extents of melting (melt extraction) whereas that beneath slow-migrating ridges has undergone greater extents of melting (e.g. Figure 4 of Klein and Langmuir, 1989) which may influence mantle convection. Further study is needed from different branches of geosciences to investigate whether the ‘deeper origin’ ridges (Su et al., 1992) have any peculiar characteristics from other ridges.

The observation that the SWIR may be tapping the same portion of the mantle as did the CIR, suggests that different portions of the mantle have undergone different phases/history of recycling, and thus offers one possible mechanism of origin of lateral heterogeneity in the mantle. A study which will involve entire ridges may reveal more of such observations (Masalu and Tamaki, 1994).

CONCLUSIONS

The absolute migration of global mid-ocean ridges for the past 85 million years and its potential role in mantle dynamics have been investigated. Absolute migration velocities and depth of origin of ridges appear to correlate, whereby slow-migrating ridges (migrating at 0.3–2.0cm/yr) have deeper depth of origin than fast-migrating ones (migrating at 3.3–5.5cm/yr). The SWIR appears to be tapping the same portion of mantle as did the CIR, a phenomenon that may explain lateral mantle heterogeneity. Active deformation which appears to be taking place between the SMAR and CMAR at least since 85 Ma is one possible explanation of the origin of tectonic complexity in the equatorial Atlantic.

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Absolute migration and the evolution of the Rodriguez Triple Junction since 75 Ma

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ABSTRACT

The Rodriguez Triple Junction (RTJ) is a junction connecting three mid-ocean ridges in the Indian Ocean: the Southwest Indian Ridge (SWIR), the Central Indian Ridge (CIR) and the Southeast Indian Ridge (SEIR). The evolution of the RTJ has been studied extensively for the past 10 Ma and the triple junction is believed to be largely a ridge-ridge-ridge (RRR) triple junction. However, due to the scarcity of data its configuration prior to that period is poorly understood. The migration of the RTJ in the hotspot reference frame, for the past 75 million years has been mapped, by reconstructing its traces on the three plates (African, Antarctic and Indian) to their former positions. The results show that the RTJ has migrated northeasterly at velocities varying from 10cm/yr at 70 Ma to 2.6cm/yr at 43 Ma and thereafter 3.6–3.8cm/yr, in a fairly straight-line trajectory, suggesting a stable configuration of the RTJ since its formation. Because the RRR triple junction is the most stable configuration that is possible, it is suggested that the configuration of the RTJ has been largely RRR triple junction since its formation.

INTRODUCTION

The Rodriguez Triple Junction (RTJ) is one of the outstanding features on the Indian Ocean seafloor. This triple junction is defined by three ridges: the Central Indian Ridge (CIR) which separates the African and Indo-Australia plates, the Southwest Indian Ridge (SWIR) which separates the African and Antarctic plates, and the Southeast Indian Ridge (SEIR) which separates the Indo-Australia and Antarctic plates. The RTJ came into existence at Chron 28 (64 Ma) when the Seychelles microplate drifted from India, giving birth to Carlsberg Ridge (McKenzie and Sclater, 1971). The evolution of the RTJ since Chron 5 (~10 Ma) has been studied extensively (McKenzie and Sclater, 1971; Tapscott et al., 1980; Patriat and Courtillot, 1984; Munsch and Schlich, 1989) and is relatively well constrained. For this period the most widely accepted model of evolution of the RTJ is alternating RRF and RRR configurations. However, the evolution of the RTJ before 10 Ma is only poorly understood due to the scarcity of geophysical data. Based on the apparently consistent configuration of the three ridges between 10 and 39 Ma (Chron 18), it has been
Figure 1. Tectonic map of the Central Indian Ocean (after Patriat and Segoufin, 1988). Thin lines are either isobath 2500 m or magnetic lineations with their anomaly number; thick lines are spreading centres as indicated; dotted lines are traces of the RTJ (TJT-Af = trace on the African plate; TJT-In = trace on the Indo-Australia plate; TJT-An = trace on the Antarctic plate)
suggested that the configuration of the RTJ did not change during this period (Dyment, 1993). Similarly, available data for the period before Chron 18 are too sparse to accurately define the RTJ, but they are sufficient to approximately define the trace of the RTJ location (Patriat and Segoufin, 1988). Based on paleogeographic reconstruction results of the central Indian Ocean to derive past positions of the spreading axes at Chron 28 and 24, alternating RRF and RRR configurations (Patriat and Courtillot, 1984) similar to the present configuration were proposed. Recently, Dyment (1993) using updated data in the central Indian basin re-examined the evolution of the RTJ between 65 and 49 Ma (Chron 28 to 21). He suggested that between Chron 29 and 24 the RTJ followed either an unstable RRR or more likely, a pseudo RRF mode: and that between Chron 24 and 21 the evolution was characterised by a predominantly RFF configuration that episodically turned to a transient RRR configuration. This paper investigates the evolution of the RTJ since 75 Ma to Present by mapping its migration in the hotspot reference frame, for the first time ever.

METHODS OF ANALYSIS AND DATA

Magnetic anomaly lineations form concurrently with new seafloor on mid-ocean ridges. On the other hand, a trace of a triple junction is a trajectory that records past locations of the triple junction (TJ). Therefore, if there exist points of intersection between a trace of a TJ and identified magnetic lineations, and a relevant model of absolute motion of the plate on which the trace of the TJ resides, absolute paleopositions of the TJ can be reconstructed by rotating the points to their former positions (Masalu and Tamaki, 1994). However, this method should be used cautiously in cases where the intersections of magnetic lineations with same age on the two sides of the trace of the TJ are significantly dislocated. In such situations, intersections that are relatively younger should be used. For each of the derived successful paleolocations (migration trajectory) from the TJ traces, the absolute migration velocity of the RTJ are computed.

In this study, Figure 1 was used as the base map from which the intersection points of magnetic lineations and the TJ traces, for all three traces of the RTJ were digitised. The reconstruction rotations were performed using Muller et al. (1993) models of absolute plate motions for the Indo-Australia, African and Antarctic plates, and assigned Chron ages based on the recent geomagnetic polarity time scale for Late Cretaceous and Cenozoic time (Cande and Kent, 1992).

Trace of the RTJ on the Indo-Australia plate

The trace of the RTJ on the Indo-Australian plate marks the intersection of the CIR and SEIR. The two ridges have quite similar spreading rates (Dyment, 1993) and as a result intersections of magnetic lineations of the same age with the TJ trace are very consistent (Figure 1). Thus there was no problem deciding which set of intersection points to digitise, for use in reconstructing the paleolocations of the RTJ.
Trace of the RTJ on the African and Antarctic plates

The trace of the RTJ on the African and Antarctic plates is not straightforward. There is one major difficulty, which is the scarcity and complexity of identified magnetic lineations formed by the CIR on the African plate (Tapscott et al., 1980; Sclater et al., 1981), and those formed by the SWIR on both the African and Antarctic plates. This prohibits the intersection points between the TJ traces and magnetic lineations that were formed by the SWIR from being accurately determined. Furthermore, based on tectonic setting of the Indian Ocean basin (Figure 1) the SWIR appears to be propagating into crust that was formed by the CIR and the SEIR. Other investigators have suggested that processes involved on the SWIR close to the TJ are more likely related to extension of the SEIR and the CIR crusts than normal spreading at the SWIR axis (Patriat and Parson, 1989; Mitchell, 1991). However, because the SWIR appears to be propagating into the crust that was formed by the CIR and SEIR, the migration trajectory of the RTJ based on magnetic lineations formed by the SWIR, may be constrained by the reconstructions based on the CIR and the SEIR magnetic lineations.

Figure 2. Reconstructed absolute paleolocations of the RTJ traces. Line with solid circles is reconstruction based on TJT-Af; line with crosses is reconstruction based on TJT-In; line with triangles is reconstruction based on TJT-An; Line with asterisks is the average reconstruction based on the three traces. Crosses, triangles, solid circles and asterisks represent Chron ages 0, 5, 6, 8, 11, 13, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, and 31 sequentially from the TJ. Note that TJT-Af does not have Chron 11, 31, and 32.
RESULTS AND DISCUSSION

Figure 2 shows the results of the reconstructions. Reconstructions based on the three TJ traces: the Indo-Australian, African and Antarctic plates, yield coincident migration trajectories for the RTJ. The RTJ appears to have been migrating northeasterly since 64 Ma (Chron 28). The migration trajectories do not indicate any major changes that could be related to instability of the RTJ. The fairly straight-line trajectory suggests that the configuration of the RTJ has been stable throughout since 64 Ma, in favour of the RRR (Ridge-Ridge-Ridge) configuration.

The northern section of the SWIR presently lies on the RTJ trajectory for the period from 52 Ma (Chron 24) to Present. This may have important geochemical and petrological implications because both mid-ocean ridges and triple junctions are locations of passive mantle upwelling and recycling.

Figure 3 shows absolute migration velocities of the RTJ. The average velocity decreased since about 65 Ma from 10cm/yr to about 2.6cm/yr at 43 Ma. Since 41 Ma to Present the migration velocity remained almost constant between 3.6–3.8cm/yr. The timing at 41 Ma coincides with the time when the Wharton ridge in the central Indian Basin became inactive (Liu et al., 1983), and the Emperor-Hawaii bend in the Pacific Ocean (Engebretson et al., 1985), suggesting a major global plate reorganisation.

Figure 3. Absolute migration velocity of the RTJ since 90 Ma to present. Thin solid line based on the TJT-An, dashed line based on the TJT-Af, dotted line based on TJT-In, and the thick solid line is the average of the three traces.
CONCLUSIONS

The absolute migration of the RTJ in the Indian Ocean for the past 75 Ma is reconstructed. This kind of study is the first ever performed for a triple junction. Reconstruction of the RTJ traces on the African, Indo-Australia and Antarctic plates gives coincident trajectories implying reliable results. Furthermore, the migration trajectories do not indicate any major changes in direction suggesting that the RTJ has had a stable configuration since 65 Ma. On this basis the RRR configuration for the RTJ is favoured. The results indicate that since 65 Ma the RTJ has been migrating due northeast. The migration velocity of the RTJ decreased from 10cm/yr at 70 Ma to about 2.6cm/yr at 43 Ma, and thereafter (at about 41 Ma) has remained almost constant at 3.6–3.8cm/yr to Present. The coincidence of the timing at 41 Ma with other major event such as the Emperor-Hawaii bend and the ‘death’ of the Wharton ridge may suggest a major global plate reorganisation. The northeastern section of the SWIR lies on the RTJ migration trajectory for 52 Ma to Present. This has important geochemical and petrological implications as far as mantle recycling is concerned.

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General characteristics of the intertidal and lagoonal sediments around Unguja Island, Zanzibar, Tanzania

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ABSTRACT

Intertidal and lagoonal sediments sampled around the Zanzibar (Unguja) Island have been analysed for their carbonate content, biogenic composition and relative abundance of the major taxonomic groups. The study shows a marked difference in both the carbonate content and the relative abundance of biogenic species between sediments collected from the eastern and western coasts of the island. The sediments from the eastern coast of Zanzibar are entirely carbonates with no siliciclastic (non-carbonate) components, while those from the western coast, particularly between the central part of the island (Mangapwani to Fumba) are composed of various proportions of carbonate and siliciclastic components. The biogenic composition of the sediments from the eastern coast of Zanzibar is dominated by Halimeda which in most cases constitute at least 50% of the bulk of the sediments. Other important biogenic groups in the sediments include molluscs (70%), benthic foraminifera (16%) and corals (10%). The biogenic composition of the intertidal sediments from the western coast is dominated by either the molluscs or the benthic foraminifera. The proportion of each of the two groups may be up to 80%. Of the two groups, the dominance of one group over the other seems to be locally influenced by the prevailing physical conditions in the area. However, the benthic foraminifera tends to be the dominant group further offshore. In the intertidal zone, coral is the third important biogenic group (18%). Exceptionally high values of up to 80% have also been found but in a very restricted area in the western side of the island. Other groups such as the crustaceans are of minor importance. Halimeda fragments are less common in this survey, and are only found at Kombeni Bay and Mangapwani (5%), which represent protected/partially-protected environments. However, near the southern and northern tips of the island (Kizimkazi and the coast west of Nungwi) the Halimeda proportion in the sediments is comparable to the typical values noted for other sediment samples on the eastern coast of the island. The difference in the sediment characteristics of the two sides
of the island is attributed to the different physical settings which characterise
the two sides. The intertidal zone of the eastern coast of Zanzibar is
dominated by wide sand flats connected to shallow and narrow lagoons
with fault scarps composed of fringing reefs toward the ocean. The depths
have a very sharp gradient from the reefs toward the continental slope,
giving rise to high wave activity, but the reefs offer good protection to the
lagoons and the intertidal sand flat from the strong waves. This
environmental setting seems to favour Halimeda growth. The benthic
foraminifera can flourish over a wide range of environmental settings and
their lower proportion on the eastern coast can be attributed to dilution
by the overwhelming abundance of Halimeda.

INTRODUCTION

Zanzibar Island (Figure 1) is one of the three major islands of Tanzania located off the
Tanzania mainland. The other two islands are Pemba, to the north of Zanzibar and
Mafia, to the south of Zanzibar. The island is approximately north-south oriented, with
a length of about 85km, width of about 35km and an area of about 1530km².

The western coast of the island is connected to the Zanzibar channel, which consists
of a 'central deep', of between 30 and 40m depth (Shaghude and Wannäs, 1998). The
central deep is flanked by raised coral platforms on the eastern side and by patch reefs on
the western side. According to Shaghude and Wannäs (1998) the eastern flank is considered
to be uplifted and faulted, while the western flank is considered to be part of an easterly
tilted block with a gentle gradient.

At the eastern coast of the island, the morphological changes from the nearshore
area towards the offshore are characterised by a nearly flat narrow topography on the
landward side of the shelf break, followed by a sharp topographic gradient on the
seaward side of the shelf break. The island itself is considered to be part of a continental
shelf which was uplifted during Early to Mid Eocene (Kent et al., 1971). Thus the
eastern coast of the island is also bounded by a fault scarp at the shelf break; the
gradient of the fault scarp is steeper than the typical topographic gradient found on the
western coast of the island. A schematic profile describing the general outline of the
geotectonic units from the mainland to Zanzibar Island is shown in Figure 2. The
continental slope is generally very narrow and the water depths at the eastern coast
changes from 10–15m near the fault scarp to more than 500m within a distance of less
than 5km at the continental margin.

The morphological structure of the eastern coast of the island consists of wide
intertidal sand flats and narrow shallow lagoons. The narrow lagoons end with a fault
scarp which is protected by fringing reefs. The presence of fringing reefs at the end of the
lagoons helps to protect the lagoons and the intertidal sand flats from strong waves from
the open ocean. The geomorphological structure of the western coast consists of narrow
Figure 1. The location map for the Zanzibar Island showing the fringing coral reefs adjacent to the coastline, the nearshore coral platforms and the sampling sites
intertidal sand flats which are connected to deeper and wider sub-tidal sand bottoms. The subtidal sand bottom deepens progressively to the channel, with no fringing reefs to protect the subtidal and intertidal sand flats from waves.

The island is fairly flat with only some minor positive relief features, particularly on the northwestern side, where the Masingini Ridge rises to about 100m above the mean sea level. The ridge is the only part of the island where the bedrock is composed of sandstones and could therefore be considered to be the source of siliciclastic sediments found on the beaches of the western coast of the island and in few patches off Zanzibar town (Shaghude and Wannäs, 1998). The main part of the island is however consisting of coralline limestone formations of Pleistocene age (Kent et al., 1971).

The tides around the island are characterised by semi-diurral tides with maximum spring tidal range of 4m. Thus, the coast can be classified as a mesotidal coast (Davies, 1964). The currents near the two coasts (eastern and western) of the island, are dominated by the East African Coastal currents which have a net northward flow. The speed of the currents varies between 0.25 and 2m/s, being fastest during the SE monsoon, which operates from May to September, and lowest during the NE Monsoon, operating from November to March. The dynamics of beach sediments are also influenced by the seasonal monsoon wind patterns. It is quite common to find accretion of a beach (e.g. the beach immediately south of the Zanzibar harbour) during one season and removal of sand on the same beach during the next season.

The wave dynamics on the two coasts is quite different. On the western coast, the waves are locally generated — they are produced by winds acting on the waters immediately adjacent to the coastline. These waves are typically short period waves,
which grow and decay quickly (Brampton, 1996). The eastern coast on the other hand is characterised by swells. These are waves that are normally generated far away from the coastline. The swells are long period waves which take some time to grow and decay. It is important to note that, although the swells are generally stronger than the locally generated waves of the western coast, the presence of fringing reefs on the eastern coast counteracts the effects of the strong swells and wind forces. Lagoonal environment characterises the intertidal sand flats of the eastern coast. On the other hand, the absence of fringing reefs on the western coast results in a relatively high agitative environment with more transport of sediments.

Sediment characteristics for the channel and the western coast of Zanzibar have been studied by Shaghude and Wannäs (1998). Furthermore, a study on the biogenic and mineralogical composition of the sediments has been conducted by Shaghude and Wannäs (in prep.). Information concerning the sediment characteristics on the eastern coast of Zanzibar is scanty. Only recently a study on the sediment characteristics and the role of Halimeda for the total sediment budget was undertaken in Chwaka bay (Muzuka et al., this volume). In the light of the differences between the environmental setting of the eastern and western coast of Zanzibar the present study will compare their carbonate content, biogenic composition and abundance of the major taxonomic groups.

MATERIALS AND METHODS

Intertidal sand samples were collected at 11 different stations (Figure 1) around Zanzibar Island. At each station, two samples were collected; one close to the high water mark and the other from the tidal flat. Four of the stations (Makunduchi, Paje, Matemwe and Nungwi-north) were on the eastern coast, and the remaining stations (Nungwi-west, Mangapwani, Maruhubi, Shangani, Mazizini, Fumba and Kizimkazi) were on the western coast. All the intertidal sand samples were collected by hand, where the top layer of sediment (about 1kg) was sampled. In addition to the intertidal sediment sampling, other sediment samples were taken in two bays (Figure 1); Chwaka bay (11 samples), and Kombeni bay (4 samples). The lagoonal bay sediments were collected using a Van Veen grab sampler.

All samples were thoroughly washed with distilled water and oven-dried at 45℃. Analysis of carbonate content was achieved using the acid-leaching method, where sub-samples of about 3g were leached with 25% dilute hydrochloric acid, and the carbonate content determined from weight lost during leaching (Shaghude and Wannäs, 1995, 1998). Biogenic analysis of the sediment involved wet sieving of the samples into four class categories (> 1.0mm, 1.0 to 0.5mm, 0.5 to 0.25mm and < 0.25mm). The class containing sediments of < 0.25mm was discarded as these grains were practically difficult to identify under the binocular microscope. The other three classes were then split into sub-samples of approximately 300 grains and using a binocular microscope,
each sub-sample was analysed by point counting of grains, identifying the different biogenic groups and tallying the number of organisms of each group.

RESULTS

Carbonate analysis
All the sediment samples collected from the eastern coast of the island were entirely carbonate sediments (with almost 100% CaCO$_3$). With regard to the sediments from the western coast, only those collected near the southern tip (Kizimkazi) and northern tip (Nungwi-west) of the island was entirely carbonates. The other samples from the western coast, particularly the central part of the island (Mangapwani to Fumba), consisted of both carbonate and siliciclastic components in the sediment (Figure 3). The tidal flat constituted variable mixtures of carbonate and siliciclastic sediments, where the carbonate proportion seem to increase southwards. The beach slope samples at these localities is dominated by siliciclastic components, with negligible carbonate components (<5%).

Biogenic analysis
The results of the biogenic analysis of the intertidal and lagoonal sediments of the western and eastern coasts of Zanzibar Island are presented in Figure 4. Whereas the sediment samples collected from the eastern coast of Zanzibar are entirely biogenic, with no lithogenic components, samples from the western coast are composed of both biogenic as well as lithogenic components.

At the eastern coast the samples are dominated by *Halimeda* which accounts for at least 50% by counts of the sediments analysed. The molluscs are the second most

![Figure 3. Carbonate content for the intertidal sediments of the western coast of Zanzibar Island](image-url)
abundant group, while corals are the third most abundant group. The molluscs are generally found in proportions between 15 and 40% of the sediments. Benthic foraminifera are found at proportion not exceeding 20%. The corals are not as widely distributed as the other three groups (Halimeda, molluscs and foraminifera), but rather, are found in a limited distribution with proportions of up to 20%, at Paje and Nungwi. Other minor groups in the sediments include crustaceans and echinoderms. The combined proportion of the minor groups ranges from 5–10% on average.

Both foraminifera and molluscs dominate sediments collected from the western coast. However, in the channel the foraminifera is generally the dominant group (Shaghude and Wannäs, in press). The Halimeda seems to be less common in the sediments collected from the western coast (Figure 4). They are however, found at

![Image a](image1.png)

![Image b](image2.png)

Figure 4. Biogenic composition and abundance (expressed as percentage by weight) of intertidal and lagoonal sediments. a = western coast; b = eastern coast
significant proportions in the intertidal sediments near the southern tip (Kizimkazi) and northern tip of the island (Nungwi-west), where their abundance is more-or-less comparable to the typical values found in other localities on the eastern coast. The *Halimeda* is also found (but with relatively low proportions) at Kombeni bay, which is in a protected environment, and Mangapwani, whose intertidal area where the present samples were collected is also in a partially protected environment.

Coral is the next important biogenic group in the intertidal sediments of the western coast which is characterised by a limited distribution of exceptional higher values of up to 80% at Mwbeni (15km south of Zanzibar town) and occurs at very low proportions (< 3%) or is absent in the remaining localities. The other minor groups again include the crustaceans and echinoderms, with a combined proportion of between 5 and 20%. The crustaceans are entirely represented by the ostracods, and in most cases they consist of up to two-thirds of the minor groups.

**DISCUSSION**

The observed difference between the carbonate content of the intertidal sediments of the eastern coast and the western coast of Zanzibar is generally related to the surface geology of Zanzibar. The northwestern part of the island is slightly elevated (with maximum relief of 100m) relative to the other parts of the island. The uplifted block (Masingini ridge) is composed of sandstones, while the remaining parts of the island consist of reef limestones. The existing drainage patterns at Masingini ridge are such that the erosional products from the sandstones from the ridge are transported to the western side of the island. When the eroded products reach the coast, they could be transported either northward by the ebb tidal currents, or southward by the flood tidal currents (Shaghude et al., in prep.). However, the fact that beach sediments at Nungwi is composed entirely of carbonates suggests that the eroded sediment when reaching the coast are preferentially transported southwards. The present study shows that the tidal flat sediments collected between Mangapwani and Fumba show a progressive increase in siliciclastic content from south to north, and this also indicates a preferential southward transport of the sediments eroded from Masingini ridge.

Another major difference between the sediments of the eastern coast and those on the western coast is observed in the biogenic abundance of foraminifera and *Halimeda*. The *Halimeda* group, which dominates the sediments from the eastern coast is relatively less important in the sediments from the western coast, and the foraminifera which are very significant in the sediments of the western coast are relatively less important in the sediments of the eastern coast.

The absence or significantly low proportion of *Halimeda* on the western coast could probably be due to the fact that the coast is relatively turbid as the intertidal sand flats are not protected from winds and wave forcing. Furthermore, the narrow nature of the intertidal sand flats found on the western coast, would not favour a wide establishment of the *Halimeda*. On the western coast, the *Halimeda* are significant
near the southern and northern tips of the island (Kizimkazi and Nungwi-west, respectively), which have similar environmental settings to that found at the eastern coast. The presence of *Halimeda* at Kombeni bay and Mangapwani, on the western coast of Zanzibar, can be explained by the fact that both of these locations are in protected (or partially protected) environments. However, the intertidal sand flats in the two locations are too narrow to allow a wide establishment of the *Halimeda* and as a result, the observed proportion of *Halimeda* in these areas is also low.

Benthic foraminifera are well established on the western coast and are relatively less common on the eastern coast. Unlike the *Halimeda* which seems to be very closely related to specific physiographical conditions, the benthic foraminifera can tolerate a wide range of marine environments, including both cold and warm waters (Lees, 1975; Rao, 1996) and inner and outer shelf sea bottom (Nelson and Bornhold, 1983; Iryu et al., 1995; Andruleit et al., 1996). A recent study on the mineralogy and biogenic composition of Zanzibar channel sediments (Shaghude and Wannäs, in prep.), revealed that the benthic foraminifera dominates (>70%) both in the reef platform areas close to Zanzibar Island as well as central channel sediments areas far offshore. Lower proportions of benthic foraminifera are found close to the mainland coastline, and this is clearly due to the siliciclastic dilution from the two major rivers, Ruvu and Wami, which bring significant amount of land-derived sediments. It seems therefore that the observed low proportion of benthic foraminifera on the major parts of the eastern coast of Zanzibar is due to (dilution by) the overwhelming abundance of the *Halimeda*.

The remaining major biogenic groups (molluscs and corals) are found in more-or-less similar proportions on the two sides of the coast, suggesting that their abundance in the sediments is probably controlled by other local factors. Molluscs seem to be well established in the sandy sea bottom as well as in muddy sea bottom. Coral fragments were often found close to the fringing reefs. One possible explanation could be the fact that the coral fragments are usually coarse and relatively denser and therefore not easily transported.

**CONCLUSIONS**

Two major differences between the intertidal and lagoonal sediments on the eastern and western coasts of Zanzibar are:

1. The intertidal and lagoonal sediments on the eastern coast are entirely biogenic, while those on the western coast constitute of siliciclastic components, which are derived from the uplifted Masingini ridge sandstones north of Zanzibar town. The existing drainage pattern is such that the weathered sediments from Masingini Ridge are normally transported toward the western coast.

2. The intertidal and lagoonal sediments on the eastern coast are dominated by *Halimeda*. The benthic foraminifera on the eastern coast is of relatively less importance in the sediments. This is contrary to what is observed on the western
coast where the intertidal sediments are generally dominated by both the benthic foraminifera and molluscs, except near the southern and northern tips of the island where the proportion of Halimeda is comparable to the typical values found on many parts of the eastern coast.

The observed major differences in the carbonate content, biogenic composition and abundance of the major taxonomic groups in the sediments of the eastern and western coast of Zanzibar are attributed to the different physical and environmental characteristics of the two coasts.

Further, the intertidal sand flats and the lagoon are well protected from waves and wind forcing by the fringing reefs, located at the end of the sand flats. A sheltered environmental setting seems to be of vital importance for Halimeda to flourish. The absence of similar fringing reefs on the western coast leaves the intertidal sand flats exposed to waves and wind forcing, an environment which does not seem conducive for Halimeda to flourish.

The intertidal sand flats and the lagoonal sediments around Zanzibar Island are dominated by three biogenic groups: Halimeda, benthic foraminifera and molluscs. Corals are also common in some intertidal sand flats, but generally at much lower proportion relative to the other three taxonomic groups. Crustaceans and echinoderms are less common and have been regarded as rare taxonomic groups in the sediments.

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Reassessment of the nature of beach erosion north of Dar es Salaam, Tanzania

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ABSTRACT
An assessment of the status of coastal erosion along the coastline of Tanzania, including the Zanzibar islands, through field surveys, revealed that the problem is widespread but more serious along the Kunduchi beach, to the north of Dar es Salaam city. Analysis of wave climate data, drogue tracking, current measurements and beach profiles obtained during both the NE-monsoon and SE-monsoon periods shows that the prevailing erosion is mainly a result of combined effects of high tidal levels and strong waves. Wave heights at Kunduchi beach are about 0.5m during the NE-monsoon period and increase to about 0.9m during the SE-monsoon. Such wave climate in combination with high tidal range of up to 4m results in increased wave erosion during high spring tides. Beach profiles made during selected periods indicate that erosion is generally more severe during the SE-monsoon period, especially during July/August/September. It was also found that erosion intensity depends on both shoreline geology and nearshore bathymetry. Owing to the nature of the bathymetry, waves are focused selectively at some sections of the shoreline while the rock type of each section determines the ease with which it erodes.

Tidal circulation in the area appears, as a rule, to flood from the north and ebb in the reverse direction. Analysis of the various drogue tracks cast seaward of the breaker zone during both the NE and SE monsoon periods shows a net southward transport which is confirmed by current measurements. Grain size data and sedimentary structures from the beach and within the breaker zone on the other hand point to a net northward transport. The contrast shows that whereas the beach and breaker zone sediment dynamics is largely driven by the action of breaking waves which are stronger during the SE monsoon, the dynamics outside the breaker zone is driven mainly by tidal circulation. The supply of sand from rivers and creeks draining into the area contributes the bulk of the sand that is being moved along the beach. The growth of large spits across creek mouths are attributable to the alongshore deflection of the ebb jets out of the creeks.
INTRODUCTION

A number of studies have been carried out on various aspects of coastal erosion in Tanzania, and in some cases the causes of coastal erosion have been suggested as follows: coastal uplift (Alexander, 1966, 1969); sea level rise (Fay, 1992); and changes in hydrodynamic conditions such as longshore drift (Arthuton, 1992). A number of workers have dwelt on issues such as the description of the status of the problem, e.g. in the Dar es Salaam area (Alexander, 1968; Schiller & Bryceson, 1978; Bryceson & Stoemer, 1980; Mushala, 1978; Rossi & St Ange, 1986; BEMC, 1987), Maziwi Island (Fay, 1992) and Zanzibar islands (Rossi and St Ange, 1986; Nyandwi, 1990; Nyandwi and Muzuka, 1991; Mohamed and Betlem, 1996; Nyandwi, 1996). There are also publications such as Shaghude et al. (1994) and Arthuton (1992) which give a general overview of the country perspective. Of the causes mentioned, sea level rise and tectonics have been very difficult to prove. Alexander (1968) found that the Holocene beach ridges north of Dar es Salaam are tectonically deformed, while the area is subsiding with greater intensity to the south where erosion is greater. The sinking old Arab buildings on the western coast of Mafia which stand several metres under water may be attributed to tectonic subsidence. Like the rest of the world, the ongoing sea level rise following the last glacial phase would be expected to add to coastal instability. When high waves coincide with high water springs they reach highest elevations and cause tremendous damage to the shore. Upon entering shallow waters, waves are refracted and diffracted leading to the concentration of wave energy along certain sections of the coastline. The direction of approach also results in the generation of longshore currents, undertow or rip currents. Tidal currents are also known to play a role in sediment movement and erosion of shorelines. Some human activities have also been observed to contribute to the erosion problem.

The significance of the various causative factors relative to one another has not been established and therefore it has been very difficult to make reliable suggestions on mitigation. As such, the status of coastal erosion has recently been surveyed and additional oceanographic data collected to assess the possible causes. This paper evaluates the existing data and describes the erosion process at Kunduchi Beach north of Dar es Salaam.

THE STUDY AREA

Tanzania has about 800km of mainland coastline and a number of islets including major and inhabited islands of Zanzibar (Unguja and Pemba) to the northeast and Mafia in the south (Figure 1a). Tanzania lies just south of the equator between 1° 00'S and 11° 45'S. The total population according to 1988 census is 23,174,336. About 3.6 million people live within the coastal zone.

A number of major and minor river entrances indent the shoreline (Figure 1b). The islands of Zanzibar are separated from the mainland by the Zanzibar Channel. The Channel is shallow, seldom deeper than 60m. At its central part the Channel is just about
Figure 1. Coastline of Tanzania: (a) General geology and coastal outline
30m deep. Outside the southern and northern entrances to the Channel depths reach 300 and 500m, respectively. Close to Kunduchi beach area the bathymetry curves landwards between 500m and 20m. The shoreline of Tanzania, like most of the East African region, is flanked seawards by a fringing reef which at localities stands exposed or just below sea surface at low tide. The tidal range of up to 4m in this region means erosion of the high beach would only be possible at high water springs. The region is swept by the monsoons which blow from the northeast during the southern hemisphere summer and from the southeast during the northern summer. The East African Coastal Current that sweeps these waters is reported to flow northwards throughout the year (Newell, 1957).

Much of the coastline is made of Quaternary formations (Figure 1a), composed mainly of unconsolidated raised beach sands, raised reef limestone and low-lying, sometimes, mangrove-covered sands. With the exception of the mangrove areas the rest are susceptible to erosion. Sediment sources appear to be the numerous streams entering the coast (Griffiths, 1987) as indicated by huge sand spits at almost all stream

Figure 1(b). Drainage pattern around Kunduchi beach north of Dar es Salaam
entrances. Owing to demand-pressure on mangrove products, most of the mangrove stands have decreased in size as compared to the recent past. The economic activities of rural coastal dwellers are mainly associated with ocean resources, mainly fishing. It has been urged that some fishing methods such as dynamiting destroy the coral reefs and enhance erosion. Other uses of the ocean and nearshore resources include sand extraction for construction, lime making from coral rocks, salt pans, ports and harbours, mangrove cutting for poles, etc. Coastal erosion has in some cases been blamed on these activities.

Erosion problems have been reported along virtually the whole stretch of the mainland coast and around Zanzibar and Mafia islands. Areas known to be severely affected include the Kunduchi beach in the Dar es Salaam area, the coastline of Mtwaralindi area to the south and Tanga in the north. The east and west coasts of Unguja island experience similar erosion problems but there is tendency towards intense erosion on the east coast. Pemba Island has less of an erosion problem as much of the shoreline is covered by mangroves.

High investments in the tourism industry and expensive homes are found along Kunduchi beach (Figure 1b). Many of the tourist hotels are already threatened by erosion. Hotel Africana (situated to the south of Kunduchi Beach Hotel) which was built on a dune had more than 50% of its residential huts lost by the late 1980s. The Kunduchi Beach Hotel was already within less than 2m of the fast encroaching sea before it was reclaimed in 1998. The hotel was built on a dune in the 1970s. Hemed (1987) found that beaches like the one in front of Silver Sands Hotel (situated to the north of Kunduchi Beach Hotel) experienced bouts of erosion and accretion in successive periods of 33 to 35 days. However, for the last 12 years or so there has been a net erosion of up to 5m per year. In the Tanga area several localities including Mwambani, Kigombe and Pangani delta are affected. An island known as Maziwi, off Pangani, is believed to have disappeared in 1977/78 as a result of sea level rise (Fay, 1992).

HYDRODYNAMICS

A number of studies have been conducted on the hydrodynamics of the coastal waters of Tanzania. Of particular significance to coastal erosion are those of Lwiza (1994) and Harvey (1977). Newell (1957) made some observations on the currents off Zanzibar but the fact that the site is relatively far from the shoreline renders the findings only indicative.

Drogue tracking

Drogue tracking experiments were carried out by Harvey (1977) and Lwiza (1994) covering both the NE and SE monsoon periods (Figure 2). The drogues were cast outside the breaker zone to avoid grounding on the reefs. As such the tracks obtained do not indicate the direction of the longshore current which usually occurs within the breaker zone. The majority of the drogues seemed to describe open loops defined by the
tidal current. The drogues which were cast in the morning moved southwards with time towards high water time, deflecting eastwards around high water before moving northwards with time towards low water time. Comparison of the relative positions of deployment and retrieval locations showed that the drogues had generally moved due south.

Current measurements

Most of the current measurements available have been made by several vessels plying the coastal waters and the recorded tidal currents are shown on British admiralty charts. Measurements made at six stations located within the Zanzibar Channel very close to the island and in the open waters as presented by Harvey (1977) are probably the most useful (Figure 3). Generally very close to the island the residual current is due north while in more open waters the current has a southerly component. It could also be shown that the tide enters the Channel from both ends and ebbs in reverse directions. This fact complements the tracks described by the drogues north of Dar es Salaam as explained above.
Figure 3. Current residuals in the Zanzibar Channel (after Harvey, 1977)

Waves

Visual observations of wave heights made during day time with the help of graduated wooden poles erected in the intertidal zone as wave staffs have given indicative estimates of wave heights during the two monsoon periods. The average wave heights are about 0.9m during the NE monsoon but increase to 1.2m and more during the SE monsoon (Table 1). The wave heights increase from Msasani Bay in the south, northwards to Ras Kiromoni where wave heights of 1.5m and higher are recorded (Lwiza, 1994). Still higher waves are expected at night especially during the SE monsoon period when generally stronger wind conditions are experienced at night. The waves approach the shore generally from the SE direction with periods of 8–10 seconds. The months of July, August and September record the highest waves. Wave measurement by wave gauges during August at Kunduchi shows significant wave heights and periods to be
about 0.4m and 6–10 sec., respectively (Figure 4). The data show that the region does not experience storms. Swells are also rare.

Table 1. Wave climate at Kunduchi beach, north of Dar es Salaam area (after BEMC, 1987)

<table>
<thead>
<tr>
<th>Location</th>
<th>NE Monsoon</th>
<th>SE Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Msasani</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Kawe ranging site (white sands)</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Africana</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Kunduchi</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Ras Kiromoni</td>
<td>1.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Figure 4. Variation of significant wave heights and periods with water depth at Kunduchi (after Dubi and Nyandwi, 1999)
SEDIMENT DYNAMICS

Granulometric studies

Sedimentological studies of the beach and nearshore sediments from the study area have been performed recently by Muzuka and Shaghude (pers. commun.) and Dubi and Nyandwi (1999). Based on the mean grain size trends along the beach the sediment shows a northward fining, more so northward of river mouths. The grain size at the beach however, varies with variation in the hydrodynamic conditions as may be shown by median grain sizes (Figure 5). Whereas at the beginning of the month of May, the median size is about 0.5mm (1 phi) the sand becomes coarser during the southerly monsoon with median value of 0.7mm (0.5 phi). The trend suggests increase in energy level which may be a result of high wave intensity during the southern monsoon period.

![Figure 5. Grain size variation during NE and SE monsoon](image)

Beach profiling

A great deal of beach profile studies have been made in the area over different periods. Hemed (1987) made beach profiles at several locations during both the NE and SE monsoon periods. With the exception of the bay area the coastal stretch showed marked erosion during the SE monsoon period while signs of accretion were evident during the NE Monsoon. This indicates the reversing nature of the longshore current with the changing monsoons (Figure 6). Erosion of the upper beach at Kunduchi appears to be intense during August in particular (Figure 7).
Figure 6. Beach profiles at Kunduchi in 1987

BATHYMETRY

The coastal waters off Dar es Salaam are characterised by the occurrence of a fringing coral reef, a number of small islets and a smooth bathymetry further offshore (Figure 8). The separations between small islands represent small openings for the wind-driven waves to become concentrated along certain parts of the shore. Most remarkable is the bathymetry between the entrance to the Dar es Salaam port and the islands fronting the study area, whereby the depth contours show a definite landward curve (between 50 and 500m depth). This bathymetry is thought to be responsible for the focusing of waves from the southeast directly to the stretch north of Dar es Salaam (Kunduchi Beach). There is also a similar opening for the waves approaching from the northeast with a similar effect.

DISCUSSION

The fact that drogue tracks outside the breaker zone indicated a net southerly direction during both the NE and SE monsoon periods indicates that tidal currents predominated over any northward wind driven current in this region, a fact supported by the findings of Harvey (1977). Inside the breaker zone and on the beach however, the northward fining of the sediment indicates a net northward longshore current, or simply a northward decrease in wave energy. The results indicate that whereas tidal currents are important in driving the circulation seawards of the breaker zone, they are not of equal importance with regard to sediment transport in the breaker zone and on the beach. The longshore sediment transport has been shown to be responsible for much of the sediment transport.
Figure 7. Fortnightly beach evolution at Kunduchi towards end of NE monsoon (top) and SE monsoon period (bottom)

along the shore within the breaker zone while the longshore component of the swash may be responsible for the longshore sediment transport on the beach face and the beach in general. Since there is a marked difference in the strength of waves between the SE and NE monsoon periods it is clear that the net transport should be in the direction of the stronger monsoon period, i.e. due north as indicated by sand spits growing northwards in front of the Kunduchi Beach Hotel. As such, sediment grain size characteristics are expected to show a northward fining trend.

The wave and current climate along the East African coast are generally controlled by the seasonal monsoon winds (Newell, 1957, 1959). During the northeast monsoon the wind-generated waves approach the coast from the northerly sector and upon
Figure 8. Bathymetry of the waters off Kunduchi

breaking produce longshore currents with a southerly component. During the southeast monsoon period the wind direction is reversed and so is the wave and current climate. As such the erosion of the coast is also expected to be periodic in pattern and intensity. The coastline of Tanzania north of Dar es Salaam city is generally exposed to both NE and SE winds, with shelter from isolated islets and a fringing reef that could be effective against waves approaching from the east.
The outline of the nearshore bathymetry points to some wave focusing through the open areas between the islets and some submarine embayments. If this were not the case wave energy would be the same along the coastal stretch. Erosion is however, much less where fossil limestone makes the shoreline. The fringing reef on the other hand acts as wave barrier. Given that much of the reef stands close to the sea surface at low water and a tidal range of about 4m it means that waves larger than 4m may not reach the beach.

Other factors, including neotectonics, sea level rise and anthropogenic activities do not really erode the beach, per se but enhance the process. The coastal strip is undergoing subsidence largely due to coastal faulting (Alexander, 1968) and probably sedimentation on the shelf. The subsidence must have resulted in rise in sea level relative to the coast and thus enhancing erosion of the higher beach. A contribution to sea level rise due to global warming and melting of the polar ice masses has not been evidenced in Tanzania. Anthropogenic activities such as erection of engineering structures, direct removal of beach sediment, coral mining, dynamite fishing and mangrove cutting, though enhancing erosion, may generally be considered of little importance. Removal of pieces of coral reef for lime making as practised in Tanzania is not likely to destroy the fringing reef to the extent of rendering it ineffective as a wave barrier. The same applies to the destruction of the reefs by dynamite fishing, because what is dynamited is the reef outside the fringing reef which normally lies below low water level, such that even when intact, destructive waves bypass it at high water to erode the beaches.

CONCLUSION

From the various studies undertaken to date, shoreline erosion along the Tanzanian coastline is mainly attributed to the action of strong waves during high tidal level. The wave heights are about 0.5m during the NE monsoon period and increase to about 0.9m during the SE monsoon. Beach profiles made during selected periods indicate that erosion could be very severe during the SE monsoon period, especially during the months of July, August and September. Tidal circulation in the area appears, as a rule, to flood from the north and ebb in a reverse direction. Evidence provided by drogue tracking seems to indicate that loss of beach sand may not be largely attributed to the tidal circulation, rather to some form of seaward transport into the breaker zone where it is caught up by the longshore current.

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Survey of the extent of human-induced beach erosion problems in Tanzania

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ABSTRACT

An assessment of the coastal erosion problems along selected stretches around the Zanzibar coastline as well as along the mainland coastline of Tanzania, indicated a significant contribution to the problem by human activities. During the study, 56 eroding beaches were examined to assess the extent of anthropogenic activities to the problem. Human-induced erosion was observed at nine sites. By interfering with natural processes, human activities either initiated erosion or enhanced its rate. The activities identified fall into three categories namely, removal of beach material, removal of the protection against wave battering and obstruction of sediment supply.

The observed human-induced erosion has occurred as a negative effect resulting from poor understanding of the natural processes. It was found that sand extraction from the beach for road construction was taking place on Zanzibar because many thought that beach sand is more needed for the roads than it is for the stability of the beach itself. Similarly, mangroves are being cleared in front of newly constructed tourist hotels because the developers are mainly concerned with having a clear view to the sea and absence of mangrove leaf litter to improve the hotel site aesthetics. As such, the mitigation measures that are to be considered in such situations are expected not to be complicated. The findings suggest that the possible negative effects of any coastal development should be considered prior to its execution. In some cases coastal managers need only to establish a catalogue of activities that may not be permissible along a given stretch of coastline.

INTRODUCTION

Coastal erosion in Tanzania has become a serious problem dating back to the early 1970s (Beach Erosion Monitoring Committee, 1987). Usually concern over beach erosion problems has been raised in areas or cases where investments placed at the shoreline were threatened. In recent years, the development of tourism has seen increased construction
of expensive beach hotels and other related infrastructure, such as roads, close to the shoreline. Thus, with the increasing coastal development the erosion problem has become more apparent and consequently the need for its management more acute.

In order to properly manage the problem, erosion rates and causes need to be known. Until now erosion rates have been established in isolated cases only (e.g. Nyandwi, 1990) and efforts to identify the causes have so far remained inconclusive. Nevertheless, much of the observed coastal erosion in Tanzania has been attributed to natural processes of hydrodynamic and geologic nature including strong waves, tides, longshore currents and tectonics (Beach Erosion Monitoring Committee, 1987; Rossi and St Ange, 1986; Nyandwi and Muzuka, 1991; Mohamed and Betlem, 1996). On the other hand the influence of human activities has not been seriously considered in Tanzania. For instance, whereas it is already established that some human activities such as the extraction of beach sand for construction contribute to the problem of coastal erosion (Nyandwi, 1996), it has remained a strong speculation that destruction of the coral reefs through dynamite fishing accelerates shoreline erosion. Therefore, the management of the erosion problem should seek to identify those human activities that contribute to the problem.

It is due to the above mentioned concerns that this paper intends to crystallise the extent of the human contribution to beach erosion in Tanzania and suggest remedial measures.

GEOGRAPHIC SETTING OF COASTAL TANZANIA

Tanzania has about 800km of mainland coastline and a number of islets including major and inhabited islands of Zanzibar (Unguja and Pemba) to the northeast and Mafia in the south (Figure 1). Erosion problems have been reported along virtually the whole stretch of the mainland coast and around Zanzibar and Mafia islands. Areas known to be severely affected include the Dar es Salaam area, Mtwar-Lindi area to the south and Tanga area in the north. The east and west coasts of Unguja island experience similar erosion problems with tendency towards intense erosion on the east coast. Pemba Island experiences less erosion, as much of the shoreline is fringed by mangroves.

Much of the coastline of Tanzania is composed of quaternary formations, mainly unconsolidated raised beach sands, raised reef limestone and low-lying mangrove-covered sands. With the exception of the mangrove areas, all the rest are susceptible to erosion. Owing to demand pressure on mangrove products, most of the mangrove stands have decreased in size as compared to the recent past (Shunula, 1990). The Tanzania shoreline, like most of the East African region, is flanked seawards by a fringing reef which at localities stands exposed or just below sea surface at low tide. The tidal range of up to 4m in this region means erosion of the high beach would only be possible at high water springs superimposed by strong wave conditions. The region is swept by the monsoons which blow from the northeast during the southern hemisphere summer and from the southeast during the northern summer (Newell, 1957). The direction of the longshore currents follow the wind reversals.
Figure 1. Map of coastal Tanzania
The economic activities of rural coastal dwellers are mainly associated with ocean resources, mainly fishing. It has been reported that some of the fishing methods, such as dynamiting destroy the coral reefs. Other uses of the ocean and nearshore resources include sand extraction for construction, lime making from coral rocks, salt pans, ports and harbours, mangrove cutting for poles, etc. Coastal erosion has in some cases been blamed on these activities (Francis et al., 1997).

METHODS

The information being presented here is a result of observations made through field surveys and data analysis. Three separate but related surveys were conducted between 1995 and 1997. Initially a field work group was formed and supervised by the Department of Environment, Zanzibar to make field observations on all beaches of Unguja and Pemba including small islets. Data were collected on among others, signs of erosion. Beach lengths were measured and features of every 500m and 50m of beach stretch recorded. Equipped with the data an assessment of the status of erosion on Zanzibar was made and problem areas related to human activities identified and visited.

Based on existing information on erosion some eroding beaches of Dar es Salaam, Bagamoyo, and Tanga on the mainland coast as well as those of Unguja and Pemba were visited. During the visits interviews were conducted with sections of the coastal community on the rates and known or suspected causes of erosion. Anthropogenic activities in the coastal zone with potential negative consequences to the shoreline stability were identified and assessed for their contribution to the problem. Issues such as sand extraction from the beach, coral boulder extraction for lime making, motorised traffic on the beach berm, construction of sea walls and jetties, cutting of mangroves, dynamite fishing, salt making, etc. were addressed.

Each shoreline visited was divided into a number of eroding beach stretches that are not connected to one another, being separated by features like headlands, mangrove stands, etc. A total of 56 eroding beach segments were recorded (31 on Unguja Island, 17 on Pemba and 3 in Tanga, 1 in Bagamoyo and 4 in Dar es Salaam).

Data were analysed on 56 contiguous segments of eroding beaches of Dar es Salaam, Bagamoyo, Tanga, Unguja and Pemba. Erosion was found to take place along sandy as well as cliffed shorelines. The cliffed shorelines that are undergoing erosion are mainly composed of raised coral reef and the erosion rates are very small except at Mwambani area in Tanga.

RESULTS

On 9 of the beaches visited, the erosion problems were observed as being clearly aggravated by anthropogenic activities. The activities that contribute to erosion problems were found to fall in the following categories: (i) obstruction of sediment supply or modification of the water flow (i.e. development of beach structures), (ii) removal of
beach material, (iii) removal of protection against wave battering, and (iv) poor planning. Each of these activities is described more fully below.

**Effects of beach structures**

Obstruction of sediment supply or modification of the hydrodynamics is brought about mainly by the construction of engineering structures. These include structures placed along the beach, e.g. sea walls and those placed quasi normal to the beach, e.g. jetties. Structures placed perpendicular to the beach impede longshore sediment transport, hence accelerated erosion downstream of the current. Sea walls on the other hand, protect areas behind them but the problem usually shifts to the unprotected ends of the wall. Poor design of the structures leads to failure and easy opening for further erosion. This is also the case when groynes are poorly spaced. Salt pans are usually connected to the sea by a channel which is closed to allow crystallisation. During the closure, water piles up at the channel mouth leading to erosion of adjacent areas especially when strong waves prevail. The following examples represent different scenarios that were encountered:

**Mtoni area**

A relatively long, jetty-like structure was erected in the 1980s at Mtoni area a few kilometres north of Zanzibar Town by the Kajima construction company for loading and offloading of construction materials. The structure, which is about 0.5m high, extends onto the tidal flats to the north of Maruhubi Restaurant. This wall can be said to have been wrongly placed because it impedes longshore sand supply. It appears that the intensive erosion at Maruhubi Restaurant to the south during the NE monsoon owes much to the structure.

**Jambiani sea wall**

The beach is mainly made of carbonate sand. At Kibigija, somewhat halfway between Jambiani and Paje on the east coast of Unguja a wall was constructed (in 1977) by the Government to protect a section of the beach from erosion. Although the wall can be said to have been effective for what it was intended, erosion has continued or shifted to the northern end of the wall where loss of land amounts to about 10m in width since 1977.

**Maruhubi sea wall**

A sea wall was constructed behind the Maruhubi Restaurant, to the north of Zanzibar Town, to protect the hotel. This wall has been renovated several times and it seems the place has seepage problems as well. The wall is very unstable. Erosion at the ends of the wall is continuing unabated.
Mkoani Jetty

The jetty at Mkoani in Pemba, is situated nearly E-W. On its northern side is a small mangrove stand which is a natural sediment sink. Immediate to the wall however, there are also signs of erosion taking place. On the southern side of the wall severe erosion is taking place. People in the area observe that intense erosion began after the construction of the jetty in the late 1980s. It appears that the erection of the jetty has led to concentration of wave energy leading to accelerated erosion. Southward longshore sediment transport does not appear to be important. Much of the sediment that is eroded from the beach is deposited on the tidal flats. It seems a sea wall may be inevitable to protect the little residential area available.

Removal of beach material

Sand for road construction in Zanzibar has been extracted from the beach. Although it is believed that sand is being taken from the western coast due to its abundance, there are all indications that the deposits are not that large. Beach sand is also extracted by local people at varying rates almost from every beach around Unguja (Mohamed and Betlem, 1996). The effects of sand extraction could be observed at one location as follows:

Unguja Ukuu

The beach located on the southern coast of Unguja is predominantly carbonate. Sand extraction has been going on for about two years (1994/95). Land loss over the two-year period amounts to a 5m wide coastal strip. According to the local people there has been a dramatic loss of beach sand and the remaining amounts are just a third of what they used to be before the beginning of the extraction. During the field visit, uprooted trees could be observed. A similar situation is expected at Chuini where sand extraction is taking place as well. Sand mining on the beaches was permitted by the Government due to lack of alternative source of quality sand required for the road construction projects. It should be pointed out that the sand that moves up and down the beach is necessary for beach stability against erosion. Its removal accelerates erosion.

Removal of protective mangrove forest

Mangroves have been cut for various reasons for centuries. However, the demand has now evidently surpassed supply and the stocks have dwindled with time. In some areas total loss of the forests has occurred. Mangroves are buffers against wave battering and slacken the tidal currents thereby enhancing sedimentation. Their removal generally encourages erosion. The following were observed:

Mbweni Beach

The area, a few kilometres to the south of Zanzibar Town, is experiencing serious erosion. Two activities both with negative effects are taking place here, namely mangrove cutting and sand extraction from the neighbouring beaches. Mangroves usually act as buffer against wave battering and their removal aggravates the problem.
Bagamoyo Beach Hotels area

The northern extremity of the area earmarked for tourist hotel development is fronted by mangrove stands. Some hotel owners have cleared the mangroves in front of their properties and the results are demonstrative. At such sites erosion rates of up to 3m in a year were observed.

Poor planning

Along most of the beaches of Zanzibar the current trend is to erect expensive beach hotels and residential houses directly on or very close to the beach. These structures are threatened by erosion right from the time of their construction. The hotels at Uroa, Chwaka and the bungalows at Uroa, both on Unguja Island, are an example. Similar situations exist in the Dar es Salaam area. Hotel African which was built on a dune had lost more than 50% of its residential huts by the late 1980s. Another hotel just to the north (Kunduchi Beach Hotel) was only 2m away from the fast-encroaching sea before reclamation was carried out in 1998 (Dubi and Nyandwi, 1999). The hotel was built on a dune in the 1970s. According to folklore, this dune emerged after the sea retreated about 2km seawards late in the 19th century to early 20th century.

RECOMMENDATIONS ON MANAGING MAN-INDUCED EROSION PROBLEMS

The general recommendations to be drawn are straightforward:

1. Sand extraction from the beach should be stopped and alternative sources, offshore or on land, should be explored. In the case of Unguja, it is possible that sand of good quality forms some of the beds in the Masingini series. This is implied by the abundance of quartz sand on the west coast where riverine supply is more pronounced. In the absence of the alternatives, importation from mainland Tanzania should be considered. Alternatively, it is possible to choose technology that does not require use of beach sand.

2. Mangrove cutting for any purpose should be discouraged and controlled more effectively. Mangrove replanting should be seriously considered.

3. Beach structures, though intended to protect the beach, may also lead to erosion. The construction of sea walls, jetties etc. must be based on both established stability criteria and effects on the environment.

4. Construction of expensive properties too close to the beaches should be discouraged. Most of the complaints and awareness of the problem come about largely because properties are threatened and not because the owners are concerned with the encroaching sea.
DISCUSSION

Although coastal erosion needs to be controlled, such attempts should be based on well established causes. In many parts of the coast, two types of management solutions which are scientifically questionable have been undertaken.

Dynamite fishing

This type of fishing destroys the coral reefs. Some section of the world scientific community believes that the blowing apart of the coral reefs accelerates shoreline erosion. The argument comes from the belief that the fringing reef or coral reefs of the coastal waters act as barrier against strong waves. This line of argument is spreading fast and coastal zone managers and government officials are pressing the fishing community to stop destroying the reefs so as to contribute in slowing the rates of erosion. Two pieces of evidence however, show that dynamite fishing does not accelerate shoreline erosion at least along the coastline of Tanzania. Firstly, dynamite fishing is a recent phenomenon dating not more than 20 years back (in the 1970s), yet erosion problems in the north of Tanzania (Tanga region) for instance, are reported (by coastal villagers) to have been of the same magnitude as today, more than 50 years back. Secondly, the large tidal range of up to 4m dictates that waves of about this height will pass over the fringing coral reef at high water springs. Waves of this size (3–4m) are strong enough to inflict damage to the shoreline. It is therefore, a dangerous conclusion to associate beach erosion with dynamite fishing in the East African region.

Mangrove reforestation

It is widely accepted that mangrove vegetation stops erosion. But it should also be understood that mangrove vegetation grows only in certain preferred environments. Replanting of mangrove trees has been encouraged in situations where indiscriminate cutting has resulted in loss of the forest. Reforestation efforts are being implemented in Tanga region (pers. observ.). However, in some places a lot of effort is being wasted as villagers are urged to plant mangroves in high energy environments where mangroves are not known to have naturally succeeded in the past. During the field work, uprooted as well as dead seedlings were observed at Kigombe in Tanga. There is no evidence of any human-induced erosion at this site. It is sad that the villagers have been made to believe that their shoreline is eroding because of the absence of mangrove forests.

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Frequency and long-term distribution of coastal winds of Tanzania

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ABSTRACT

Wind data records of four major coastal locations (Tanga, Dar es Salaam, Zanzibar and Mtwara) of Tanzania covering the period between 1972 and 1996 were analysed to determine maximum winds’ frequency, long-term distribution and general trends. Results show that Tanga, Dar es Salaam and Mtwara experienced peak speeds during July/August and Zanzibar experienced peak speeds in January. At Mtwara, maximum wind speeds have been linearly increasing since 1972, whereas at the other three locations, the speeds show a decreasing trend. The mode for Mtwara is 30 knots and that for Tanga, Zanzibar and Dar es Salaam is 20 knots. Mtwara has the highest location parameter $B = 26$, followed by Zanzibar and Tanga with $B = 20$. Dar es Salaam has the lowest of them all. In terms of wind activity, Mtwara and Zanzibar experienced offshore winds, while Dar es Salaam was more influenced by coastal winds. Of all the coastal locations, Mtwara experienced the strongest winds, which certainly resulted in increased wave activity, stronger currents and wind set-up.

INTRODUCTION

The United Republic of Tanzania is located on the eastern coast of Africa, between $1^\circ$ 00' – $11^\circ$ 48' S and $29^\circ$ 30' E. It is composed of Mainland Tanzania and the Islands of Zanzibar (Unguja and Pemba). The Indian Ocean borders its entire eastern frontier (Figure 1). Tanzania has an estimated total land area of 945,200km$^2$ with mainland Tanzania covering an area of 942,800km$^2$. The Zanzibar islands cover 2400km$^2$.

The coastline of Tanzania extends for about 800km on the mainland, 430km around Unguja Island and 450km around Pemba Island. The coastline of Mainland Tanzania extends from the border with Kenya in the north to Ruvuma River in the south (Figure 1). The coastal zone of Tanzania includes five administrative regions—Tanga, Coast, Dar es Salaam, Lindi and Mtwara, as well as the three large islands—Unguja and Pemba (which make up Zanzibar) and Mafia—and numerous islets. About two thirds of the coastline has fringing reefs, often close to the shoreline, broken by river outlets such as the Rufiji Delta, Pangani, Ruvuma, Wami and Ruvu. The continental shelf is
about 5.8km wide, except at the Zanzibar and Mafia channels where the continental shelf reaches a width of about 62km. The nation's total estimated shelf area is 17,500km².

The coastal waters of Tanzania are influenced by two alternating seasons; namely the southerly and northerly monsoons (Newell, 1957). The southerly monsoons,
beginning in April and ending in October/November, are usually strong and predominantly southerly. The northerly monsoons begin in November and end in March. These are lighter winds and are predominantly northerly. Circulation of the coastal waters of East Africa is strongly influenced by these winds. The East African Coastal Current (EACC) is an important hydrographic feature of the East African coastal waters. Newell (1957) described the current as one that moves northward throughout the year, but changes speeds during the two monsoon seasons. During the southerly monsoons, it moves with a speed of about 4 knots after being accelerated by the trade winds. During the northerly monsoons, the current is retarded by the northerly winds along this coast. From the equator northwards, it is reversed to flow in the southerly direction. The reversed current meets the much-decelerated EACC at about 1°S, where both are deflected out to the sea forming the Equatorial Counter Current (Figures 2a and 2b).

As wind has multiple effects on ocean circulation, waves and sea level fluctuations, it is important to study wind patterns in order to evaluate the frequency of maximum wind speeds, the distribution and return speeds of extreme winds. In order to evaluate extreme wind speeds, annual maximum series are fitted to some distribution functions. The commonly employed functions are the Fisher-Tippett (FT) type I & II, the Weibull and log-normal distributions. Other formulae are also cited in the literature. Petruaskas and Aagaard (1970) presented a procedure to select the best fitting distribution function among a set of the Weibull and the FT-I distributions advocating the Weibull distribution. According to Goda (1988), the use of the log-normal distribution should not be considered until positive evidence for its support is produced. Dubi (1999) used Goda’s method to evaluate extreme wind speeds of coastal Tanzania.

Lwambuka (1992) compiled 18-year wind data of several locations in Tanzania including Tanga, Zanzibar, Dar es Salaam and Mtwa. Using the method of moments, he fitted only the FT-I distribution function and found 50-year extreme gust speeds (1.9 x extreme wind speed) to be 30m/s for Tanga, 29m/s for Zanzibar, 27m/s for Dar es Salaam and 38m/s for Mtwa.

This paper is a complement for the paper by Dubi (1999) on the evaluation of extreme wind speeds in relation to the design of coastal structures in Tanzania. The main objectives of the present paper are to evaluate the frequency of the maximum wind speeds and their cumulative distributions, and to review statistical and other parameters related to the winds. This information is required in the evaluation of wave climate and currents in the coastal waters of Tanzania.

**DISTRIBUTION FUNCTIONS FOR EXTREME VALUE ANALYSIS**

As there is no strong theoretical or empirical evidence for selecting a particular probability distribution function, the approach commonly used is to try several candidate distributions with each data set and select the one that fits best. Following Goda (1988), Dubi (1999) fitted two distribution functions to the annual maximum wind speeds to find extreme wind speeds and 50- and 100-year return wind speeds. The candidate
Figure 2a. North East Trade Winds (adapted from Linden & Lundin, 1996)
Figure 2b. South East Trade Winds (adapted from Linden & Lundin, 1996)
distributions are:

The Fisher-Tippett Type I (FT-I) Distribution given by:

\[ F(V) = \exp(- \exp(-(V - B) / A)) \]  \hspace{1cm} (1)

and

The Weibull Distribution given by:

\[ F(V) = 1 - \exp[-((V-B)/A)^k] \]  \hspace{1cm} (2)

where \( F(V) \) is the probability of non-exceedance of the statistical wind speed variable \( V \), \( B > V \) is the location parameter, \( A \) is the scale parameter and \( k > 0 \) is the shape parameter.

The input data are then arranged in descending order of magnitude from the largest to the smallest of the wind speeds. Then a probability or plotting position is assigned to each wind speed using Gringorten's (1963) formula for FT-I and the modified formula (by Goda, 1988) of Petruaskas and Aagaard (1970) as follows:

\[
\begin{align*}
F(V_m) &= 1 - \frac{m - 0.44}{N_T + 0.12} \quad \text{for FT-I} \\
F(V_m) &= 1 - \frac{m - 0.20 - \frac{0.27}{\sqrt{k}}}{N_T + 0.20 + \frac{0.23}{\sqrt{k}}} \quad \text{for Weibull}
\end{align*}
\]  \hspace{1cm} (3)

where \( F(V_m) \) is the probability of the \( m \)-th value of wind speed not being exceeded, \( m \) being the rank of the wind speed. \( N_T \) is the total number of events during the length of a record, which in our case, has been taken to be equal to the number of input wind speeds.

The scale and location parameters \( A \) and \( B \) in equations (1) and (2) are related linearly as:

\[ V_m = AY_m + B, \quad m = 1, 2, \ldots, N \]  \hspace{1cm} (4)
where \( V_m \) is the m-th largest value of the wind speed and \( Y_m \) is the reduced variate for the m-th value of the wind speed. This reduced variate is related to \( F(V_m) \) as:

\[
\begin{align*}
Y_m &= \begin{cases} \\
- \ln[-\ln F(V_m)], & \text{for FT - I} \\
- \ln [1 - F(V_m)] \frac{1}{k} & \text{for Weibull}
\end{cases}
\end{align*}
\]

(5)

The parameters \( A \) and \( B \) are evaluated using the Least Squares method applied between the ordered pair of \( V_m \) and its reduced variate \( Y_m \) for the two candidate distribution functions.

Wind speeds for various return periods are calculated by the following equations (Goda, 1988):

\[
V_r = Ay_r + B
\]

(6)

where

\[
V_r = \text{wind speed with return period } T_r
\]

\[
y_r = \begin{cases} \\
- \ln \left[- \ln \left(1 - \frac{1}{\lambda T_r} \right) \right] & \text{for FT - I} \\
\left[ \ln (\lambda T_r) \right] \frac{1}{k} & \text{for Weibull}
\end{cases}
\]

(7)

\[
\begin{align*}
\lambda &= \frac{N_p}{K} = \text{average number of events per year} = 1 \text{ in this analysis.} \\
T_r &= \text{return period in years and } K = \text{length of record in years}
\end{align*}
\]

Since the period of record for this data is relatively short and the level of uncertainty in extreme estimates with long return periods is high, confidence intervals are calculated to give a quantitative indicator of the level of uncertainty in the estimated extreme wind speeds.

Confidence intervals are calculated following the approach of Goda (1988) for estimating standard deviation of return values when the true distribution is known. Table 1 gives factors by which the standard error is multiplied to get bounds with various levels of confidence.
Table 1. Confidence interval bounds for extreme wind speeds

<table>
<thead>
<tr>
<th>Confidence level (%)</th>
<th>Confidence interval bounds around $V_r$</th>
<th>Probability of exceeding upper bound (%)</th>
</tr>
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<tbody>
<tr>
<td>80</td>
<td>± 1.28σ</td>
<td>10.0</td>
</tr>
<tr>
<td>85</td>
<td>± 1.44σ</td>
<td>7.5</td>
</tr>
<tr>
<td>90</td>
<td>± 1.65σ</td>
<td>5.0</td>
</tr>
<tr>
<td>95</td>
<td>± 1.96σ</td>
<td>2.5</td>
</tr>
<tr>
<td>99</td>
<td>± 2.58σ</td>
<td>0.5</td>
</tr>
</tbody>
</table>

In order to select the best fit distribution function, the correlation between variables in the linear equation (4) and the sum of the squares of residuals are used. The sum of the squares of residuals is given by:

$$R^2 = \sum_{m=1}^{N} \left[ V_m - (AY_m + B) \right]^2$$  \hspace{1cm} (8)

The distribution function that gives the highest correlation and the smallest sum of the squares of residuals has been selected.

DATA SET

Wind data records for Tanga, Dar es Salaam, Mtwara and Zanzibar for the period between 1972 and 1996 were obtained for analysis from the respective airport authorities. These 3-hourly records of wind speeds and direction at airport stations are recorded by a rotating cup anemometer mounted at the top of a 10-meter high tower. The maximum value in every month for each location was taken to constitute the data set. Figure 3 shows the maximum wind speeds recorded for each month of the 25-year period. Figure 4 shows maximum wind speeds in each year of the 25-year period.

RESULTS

General trend of maximum wind speeds

Figure 3 reveals peak speeds of the maximum speeds during January and July. Tanga and Zanzibar experienced peak speeds in January, while Mtwara experienced peak speeds July. Dar es Salaam experienced peak speeds during both January and July.

Figure 4 shows that maximum wind speeds at Mtwara have been linearly increasing since 1972, whereas at the other three locations, the speeds show a decreasing trend. Zanzibar winds also exhibit a peak in the period 1979–1982. Dar es Salaam winds show two peaks: one peak is seen in the period 1975–1979 and another during 1981–84, after which the speeds decrease. Tanga winds exhibit two peaks: one in the period 1974–1977 and another during 1991–1993.
Figure 3. Monthly maximum wind speeds recorded in the period 1972–96

Figure 4. Annual maximum wind speed recorded in the period 1972–96

Frequency of occurrence and cumulative distribution of maximum wind speeds

Figures 5–8 show the frequency of occurrence and cumulative distribution of the maximum wind speeds. Some of the statistical parameters are shown in Table 2.
Based on the correlation coefficient and the sum of the squares of residuals, Dubi (1999) selected distribution functions that fitted best. They were Weibull \((k = 1.0)\) for Tanga winds, FT-I for Zanzibar winds, Weibull \((k = 2)\) for Dar es Salaam and Mtwarra winds. Model parameters corresponding to the distribution functions are shown in Tables 3–6. The selected distribution function is shown in bold and italic format.

Figure 5. Frequency of occurrence and cumulative distribution of Tanga winds

![Graph](image1)

Figure 6. Frequency of occurrence and cumulative distribution of Zanzibar winds

![Graph](image2)
Figure 7. Frequency of occurrence and cumulative distribution of Dar es Salaam winds

Figure 8. Frequency of occurrence and cumulative distribution of Mtibara winds

Table 2. Statistical parameters of the maximum wind speeds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tanga</th>
<th>Zanzibar</th>
<th>Dar es Salaam</th>
<th>Mtibara</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (kts.)</td>
<td>20.2</td>
<td>21.5</td>
<td>20.3</td>
<td>27.3</td>
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<td>20.0</td>
<td>20.0</td>
<td>30.0</td>
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<tr>
<td>Minimum (kts.)</td>
<td>18.0</td>
<td>16.0</td>
<td>15.0</td>
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<tr>
<td>Maximum (kts.)</td>
<td>27.0</td>
<td>30.0</td>
<td>26.0</td>
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Table 3. Tanga winds (Mean of sample data = 20.20 knots, std = 2.708 knots)

<table>
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<tbody>
<tr>
<td>( A )</td>
<td>2.056</td>
<td>1.730</td>
<td>\textbf{2.736}</td>
<td>4.026</td>
<td>5.529</td>
</tr>
<tr>
<td>( B )</td>
<td>19.047</td>
<td>18.150</td>
<td>\textbf{17.472}</td>
<td>16.535</td>
<td>15.302</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.9330</td>
<td>0.9435</td>
<td>\textbf{0.9559}</td>
<td>0.9449</td>
<td>0.9182</td>
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<tr>
<td>Sum of squares of residuals ( (R^2) )</td>
<td>0.2739</td>
<td>0.5444</td>
<td>\textbf{0.2016}</td>
<td>0.2447</td>
<td>0.3159</td>
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<table>
<thead>
<tr>
<th>Return period (yrs)</th>
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<tbody>
<tr>
<td>50</td>
<td>27.07</td>
</tr>
<tr>
<td>100</td>
<td>28.51</td>
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Table 4. Zanzibar winds (Mean of sample data = 21.458 knots, std = 3.007 knots)

<table>
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</tr>
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<tbody>
<tr>
<td>( A )</td>
<td>\textbf{2.385}</td>
<td>1.885</td>
<td>3.030</td>
<td>4.577</td>
<td>6.467</td>
</tr>
<tr>
<td>( B )</td>
<td>\textbf{20.123}</td>
<td>19.226</td>
<td>18.437</td>
<td>17.292</td>
<td>15.729</td>
</tr>
<tr>
<td>Correlation</td>
<td>\textbf{0.9733}</td>
<td>0.9234</td>
<td>0.9521</td>
<td>0.9662</td>
<td>0.9662</td>
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<tr>
<td>Sum of squares of residuals ( (R^2) )</td>
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<td>0.2523</td>
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<table>
<thead>
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<td>50</td>
<td>\textbf{29.43}</td>
</tr>
<tr>
<td>100</td>
<td>\textbf{31.09}</td>
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</table>

Table 5. Dar es Salaam winds (Mean of sample data = 20.00 knots, std = 2.828 knots)

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</thead>
<tbody>
<tr>
<td>( A )</td>
<td>2.246</td>
<td>1.712</td>
<td>2.809</td>
<td>4.312</td>
<td>\textbf{6.161}</td>
</tr>
<tr>
<td>( B )</td>
<td>18.742</td>
<td>17.973</td>
<td>17.199</td>
<td>16.074</td>
<td>\textbf{14.541}</td>
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<tr>
<td>Correlation</td>
<td>0.9747</td>
<td>0.8914</td>
<td>0.9382</td>
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<td>\textbf{0.9787}</td>
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</table>

<table>
<thead>
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<th>Return period (yrs)</th>
<th>Return wind speed (knots)</th>
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<tbody>
<tr>
<td>50</td>
<td>27.51</td>
</tr>
<tr>
<td>100</td>
<td>29.08</td>
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Table 6. Mtwara winds (Mean of sample data = 27.292 knots, std = 3.712 knots)

<table>
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<tbody>
<tr>
<td>$A$</td>
<td>2.875</td>
<td>2.137</td>
<td>3.525</td>
<td>5.463</td>
<td>7.894</td>
</tr>
<tr>
<td>$B$</td>
<td>25.682</td>
<td>24.760</td>
<td>23.777</td>
<td>22.318</td>
<td>20.298</td>
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<tr>
<td>Correlation</td>
<td>0.9503</td>
<td>0.8480</td>
<td>0.8970</td>
<td>0.9342</td>
<td><strong>0.9554</strong></td>
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<tr>
<td>Sum of squares of residuals ($R^2$)</td>
<td>0.1240</td>
<td>0.3303</td>
<td>0.2301</td>
<td>0.1653</td>
<td><strong>0.1161</strong></td>
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</tbody>
</table>

<table>
<thead>
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<th>Return period (yrs)</th>
<th>Return wind speed (knots)</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>36.90 37.93 37.57 36.79 35.91</td>
</tr>
<tr>
<td>100</td>
<td>38.91 41.13 40.01 38.58 37.24</td>
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</tbody>
</table>

CONCLUSION

Coastal processes and hydrographic conditions of near-shore and offshore waters are strongly influenced by winds. From an examination of the monthly and annual maximum wind speeds, the response of beaches and coastal water circulation can be deduced. Beginning 1986 until 1996 Mtwara experienced increasing maximum winds reaching a peak of 35 knots. This trend certainly resulted in increased shoreline retreat due to increased wave activity, stronger currents and wind set-up. Maximum values of Tanga winds show a peak in the periods 1972–1976 and 1990–1993. Zanzibar winds had a peak in 1979–1981. These are the periods in which increased coastal processes are expected.

Zanzibar and Mtwara have the same location parameter, $B$, which is approximately 20, followed by Tanga with a parameter 17.5. Dar es Salaam has the lowest of all. In terms of wind activity, Zanzibar and Mtwara experience offshore winds, while Dar es Salaam is more influenced by coastal winds. Tanga is influenced mostly by offshore winds. Of all the coastal stations, Mtwara experienced the strongest winds, while Dar es Salaam experienced the weakest winds.

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Heavy metal inhibition of calcification and photosynthetic rates of the geniculate calcareous algæ *Amphiroa tribulus*

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**ABSTRACT**

*Amphiroa tribulus* (Rhodophyceae, Corallinaceae) is common in the reefs near Zanzibar town, but it may be threatened by high levels of pollutants from sewage outlets of Zanzibar Town and other land-based sources. For this reason, laboratory experiments were conducted to investigate the effects of short term (4 days) and long term (8 days) exposure of the algae to selected heavy metals, calcium and a herbicide dichlorodiphenyl dimethyl urea (DCMU) on its calcification and photosynthetic rates. In this investigation, mercury (Hg), copper (Cu), cadmium (Cd), zinc (Zn), nickel (Ni), manganese (Mn), calcium (Ca) and lead (Pb) in the form of their chlorides were used. During short-term exposure, it was observed that mercury was the most toxic element. 10μM of mercury reduced the photosynthetic rate to about 45% and 100μM was lethal. The metal toxicity follows the trend Hg > Cu > Cd > Zn > Ni > Pb > Mn, with manganese showing no visible effect. The effect of DCMU was comparable to that of cadmium. Calcium had no effect on calcification rates. During long term exposure a similar trend in toxicity to calcification was observed. However, heavy metals such as Mn which appeared less toxic during short-term exposure, showed a significant inhibition of calcification rate even at lower metal concentration. We suggest that cell walls in *A. tribulus* provide active sites for heavy metal attachment and that the interference of such heavy metals with calcification and photosynthetic processes increases with prolonged exposure and/or increased concentration of the heavy metal in the growth medium.

**INTRODUCTION**

The term heavy metals refers to metals having higher atomic weight than that of iron (59g) and with density greater than 5g/cm\(^3\) (Serantino, 1979). In the natural aquatic
environment, such metals occur at low concentrations (nanogram to micrograms per litre). Occurrence of heavy metals in excess of the mentioned natural loads indicates the presence of additional external sources.

When in low concentrations, some heavy metals such as Cu, Mn, Zn, Mo and Ni are essential elements or micronutrients (Lobban and Harrisson, 1994). For example: Manganese plays an important role as a co-factor in photosystem II and in enzymes of the tricarboxylic acid cycle; copper is important in redox reactions and nickel forms part of the enzyme urease. Nevertheless these elements (in form of cations) are toxic to algae when they are present at higher concentrations.

Calcified red algae species constitute one of the essential groups of organisms that form biotic reefs, without which the solid limestone structure of the reef would soon be worn away by ocean swells. Species such as Lithophyllum kotschyanum, Mesophyllum funafutense and those of Neogoneolithon spp., cement together components of the reef to hard rocks. Species of the genera Amphiroa and Jania have upright, tree-like structures which, when they die, produce calcareous sediments which add fill to crevices in the reef structure and also contribute sand to the shore line (Borowitzka and Larkhum, 1986).

Calcification simply refers to the precipitation of CaCO$_3$ within or on the alga cell wall (Borowitzka, 1982). Observations show that other salts such as MgCO$_3$ can be precipitated together with CaCO$_3$ or as separate entities in the cell wall (Milliman et al., 1974). Moreover, it is well known that CaCO$_3$ is precipitated into the algal cell wall as a direct result of the high pH (up to 10.5) and the presence of sufficient calcium ions (Ca$^{2+}$). In such a medium the solubility product of the CaCO$_3$ is known to exceed saturation (Borowitzka, 1982).

Among the Rhodophyceae calcification occurs in Corallinaceae and in some members of Bangiales, Gigartinaceae and Squamariceae. They deposit two different forms of calcium carbonate, either calcite or aragonite. Calcite is the more stable form, where limestone consists mostly of calcite crystals. However, observations have shown that, aragonite is the most common form which is mostly precipitated inorganically in seawater (Milliman et al., 1974). Calcite forms the rhombohedral carbonate minerals and has two cations, while the aragonite forms the orthorhombic minerals with three cations for every oxygen atom. Cations such as Mg$^{2+}$, Fe$^{2+}$, Cu$^{2+}$, Zn$^{2+}$ and Mn$^{2+}$ are small and hence are energetically favoured as part of the rhombohedral (calcite) polymorph, while bigger cations such as Sr$^{2+}$, Pb$^{2+}$ and Ba$^{2+}$ are included in the orthorhombic (aragonite isomorph). Calcium is unique in that it has an intermediate ionic radius (0.99 Å), thus can form both rhombohedral and orthorhombic carbonates (Milliman et al., 1974). However, the presence of high concentration of heavy metals and cations such as Zn$^{2+}$, Ni$^{2+}$, Cd$^{2+}$ and Hg$^{2+}$ in seawater may inhibit the precipitation of the calcite (Kitano and Hood, 1962). Such inhibition is sometimes known as crystal poisoning (Simkiss, 1962). Therefore, the ionic composition and strength of the medium in which the algae grows may have an influence on the precipitation of CaCO$_3$ by the
algae. Previous studies on heavy metal load in macroalgae at different stations along the Zanzibar channel shows that heavy metal load have significantly increased in some species of macroalgae since 1989 (Engdahl et al., 1998; Ferletta et al., 1996).

Despite calcification being one of the important structural processes in the oceans, its mechanism in algae is not well known. Currently, it is known that calcification is directly proportional to the photosynthetic rate (Borowitzka, 1977), and that calcification rate is highest in the young tissues (Lobban and Harrisson, 1994). In this study, the impact/effect on photosynthesis and calcification rates of an important calcareous alga, *Amphiroa tribulus* of the heavy metals mercury, cadmium, lead, manganese, nickel, zinc and copper and a herbicide dichlorodiphenyl dimethyl urea (DCMU) were assayed. It has also been established that components of domestic sewage negatively affect the calcified algae (Bjork et al., 1995). With respect to the type of CaCO₃ deposited, location and organisation of the cell wall matrix, it appears that the calcification process in algae involves more than one mechanism (Borowitzka, 1982). Crystal formation requires two steps: crystal nucleation and crystal growth. Nucleation is the major rate limiting step for the precipitation of CaCO₃, and can be used to explain why other algae do not calcify.

**MATERIALS AND METHODS**

**Sample collection**
The calcareous alga species used in this experiment was *Amphiroa tribulus*. Fresh samples were collected by scuba diving from Bawe Island west of Zanzibar Town (Figure 1) at depths between 4 and 6m. Plant samples for the experiment were cleaned out of epiphytes soon after arrival from the field.

**Assessing the effect of heavy metals on calcification rates**
The experiment was run outdoors in full sunlight and the calcification rate was determined by estimating the rate of removal of CO₃²⁻ from the seawater using the total alkalinity method (Anderson and Robinson, 1946). Alkalinity is defined as the ability of water to neutralise hydrogen ions. The change in total alkalinity of the seawater is proportional to the change in HCO₃²⁻. For each heavy metal, mercury, cadmium, lead, manganese, nickel, zinc, copper, a herbicide dichlorodiphenyl dimethyl urea (DCMU) and calcium, a set of six series was designed. Each series contained eight Ehrlemyer flasks, set up with contents as follows:

- Series 1: Seawater only (50ml)
- Series 2: Seawater + 2g of algae
- Series 3: Seawater + 2g of algae + 0.1µM of heavy metal
- Series 4: Seawater + 2g of algae + 1.0µM of heavy metal
- Series 5: Seawater + 2g of algae + 10µM of heavy metal
- Series 6: Seawater + 2g of algae + 100µM of heavy metal.
The elements used in the experiment were added to the incubation medium (except DCMU) in the form of their chlorides and only one metal was used at a time. During incubation the flasks were continuously aerated while the temperature was maintained between 28 and 30°C using a water bath and full sunlight between 2400 and 2600μmole photons/m²/s. Incubation lasted for 4 hours and the total alkalinity was measured according to Anderson and Robinson (1946). In this method the pH of 4ml of the growth medium was measured before and after the addition of 0.01M HCl and the change in buffer capacity was calculated. Since change in alkalinity is directly proportional to the change in carbonate uptake, the decrease in alkalinity was used as a measure of $\text{CO}_3^{2-}$ used for calcification.
The differences between mean pH values of the flasks without algae (series 1) and those with algae but without heavy metal addition (series 2) were calculated and the results were compared with those under series 3–6 to determine the influence of a given metal's addition on calcification. Calculations on calcification rate were done according to Anderson and Robinson (1946). All experiments were repeated four times and the reported results show the mean value of the four experiments.

**Photosynthetic rates**
This was carried out according to the oxygen evolution method described by Kangwe (1999).

**RESULTS**
Values for the acute toxicity of elements used in this experiment are presented in Figures 2 to 9. Among the elements used, mercury was the most toxic. It reduced significantly both calcification and photosynthesis at 10µM and caused both processes to cease at 100µM (Figure 2). Cadmium negatively affected the calcification rates at 0.1µM, giving low photosynthetic rates from 0.1µM to 1µM followed by a rise in photosynthetic rates from 1µM to 100µM concentrations (Figure 3). Surprisingly and not consistent with the other metals in the survey, the calcification rate was reduced more than the photosynthetic rate. It was also found that respiration was heavily affected at high concentration of cadmium, increasing by 60% from 1µM to 100µM. Lead seems to have less toxic effects on calcification and photosynthesis rates. However, it brings a low inhibition on these processes at a concentration of 100µM and a stimulated calcification rate from 0.1µM to 10µM (Figure 4).

![Graph](image)

**Figure 2.** Toxicity of 0–100µM mercury on photosynthesis and calcification rates of *Amphiroa tribulus*
Figure 3. Toxicity of 0–100μM cadmium on photosynthesis and calcification rates of *Amphiroa tribulus*

Figure 4. Toxicity of 0–100μM lead on photosynthesis and calcification rates of *Amphiroa tribulus*

Calcium seemed to have no effect on calcification and photosynthetic rates. Possibly the ambient concentration of Ca$^{2+}$ in seawater seems not to be a limiting factor for calcification. Addition of Ca$^{2+}$ to seawater did not increase calcification rate. DCMU was used to distinguish between effects of inhibition on photosynthesis and crystal poison (Figure 5). Inhibition effects of nickel and zinc were observed from 10μM to 100μM (Figures 6 and 7). At lower concentrations there was an insignificant decrease in both calcification and photosynthetic rates. Manganese did not show any effect on calcification or photosynthesis (Figure 8). Copper was second in toxicity. It affected the photosynthetic rate at above 10μM (Figure 9). A concentration of 10μM Cu$^{2+}$ was lethal to the algae if exposed for longer than 3 days. However, there was a parallel decrease in calcification and photosynthetic rates from 0.1μM to 10μM with an increase in respiration rates at higher concentration. The results for the prolonged exposure of algae to heavy metals
Figure 5. Toxicity of 0–10μM DCMU on photosynthesis and calcification rates of *Amphiroa tribulus*

Figure 6. Toxicity of 0–100μM nickel on photosynthesis and calcification rates of *Amphiroa tribulus*

(data not shown) were consistent with the results on acute toxicity. However, some of the heavy metals which did not show significant effects after the 4 hours incubation, showed significant effects with increasing time of incubation. For example, in the prolonged incubation zinc showed its effect on calcification rate at 100μM concentration after 3 days during long term incubation. Lead continued to have little effect on calcification rate,
photosynthesis and respiration rates even at higher concentration.Nickel showed effects after 5 days of exposure. The increase in cadmium resulted in a linear decrease in calcification rates consistent with the acute toxicity experiment.

DISCUSSION

The present observations agree with the previous studies on heavy metal toxicity on algae (Rai and Kumar, 1980; Stromgren, 1979; Wong et al., 1979). As is shown elsewhere, mercury was the most toxic element. The physiology behind its toxicity was not investigated. However, in Lobban and Harrisson (1994) reduction in chlorophyll content following mercury
exposure has been shown in *Fucus spiralis*. In another study, Stromgren (1980) showed a 50% reduction in growth rate of five intertidal fucales when exposed to mercury concentration of 100–200g/l (approximately, 0.5–1μM) for 10 days. In adult *Fucus spiralis* reduction in growth was seen at 5–9μMg/l (approximately 0.025–0.045μM). Moreover, Markham et al. (1980) found that the growth of sporophyte diminishes at concentration of 36μM cadmium. Smith (1973) studying the effect of lead (in the form of PbCl₂) observed that growth of the sporophyte of *Laminaria* diminished when exposed to 17.8μM cadmium. Acute toxicity of cadmium on green algae was reported by Wong et al. (1979). However, the acute toxicity level reported by Wong et al. (1979) was significantly higher than the 10μM used in this study. This is possibly due to the difference in toxicity tolerance between algal species. Studies by Wong et al. (1979) showed that cadmium was able to inhibit the uptake of ¹⁴CO₂ for photosynthetic activities. Moreover, another study on several algae showed weak toxicity of lead on photosynthesis and respiration rates (Rivkin, 1979). However, the latter authors did not show the actual concentrations used for cadmium and lead.

Although copper is an essential micronutrient, it was shown in this study to be the second most toxic element after mercury. According to Sunda and Guillard (1976) its toxicity mostly depends on the presence of free copper ions (Cu²⁺) in the medium. Cu²⁺ can affect the permeability of the plasmalemma leading to the loss of potassium ions (K⁺) from the cell (Wong et al., 1979). When transported to the chloroplasts copper can inhibit photosynthesis by interfering with the electron transport system and eventually causing death of macrophytes (Lobban and Harrisson, 1994). Because of such toxicity to macrophytes, copper-containing antifouling agents are commonly used on ships, boats and other marine vessels.

The toxicity of other elements such as Zn, Ni and Mn to macrophytes is considered to be mild and consequently little research has been conducted so far. For example,
zinc has been shown to be actively taken by algae (Skipness et al., 1975) and Stromgren (1979) observed that 5 to 10 g/l of zinc were required to cause 50% reduction in growth of intertidal Fucales.

The metal toxicity in this study followed the trend: Hg > Cu > Cd > Zn > N > Pb > Mn. Similar findings have been reported by Rai and Kumar (1980) and Kitano and Hood (1962). The decrease in both calcification and photosynthesis observed in this study agrees with the previous observation that calcification depends on the photosynthetic processes; that is, if photosynthesis decreases, calcification will follow (Borowitzka, 1977). Moreover the present findings are also in agreement with the CO₂/HCO₃- usage theory on algal calcification. The observed effects of DCMU which is a photosystem II inhibitor, shows a big difference between calcification and photosynthetic inhibition in the untreated algae when compared to the metal treated ones. The parallel decrease in photosynthesis and calcification for these metals and the photo system inhibitor, DCMU is a direct indication that when the metals inhibit photosynthesis they indirectly inhibit calcification. This supports the studies by Lobban and Harrisson (1994) and Borowitzka (1981) that metabolic activity has a greater influence on the calcification process than the physical effect as a crystal poison. The observed effect of continuous exposure to the less toxic compounds such as manganese shows how the algae can be affected after accumulation of the toxins in their walls. At the start the algae may be able to resist the effect at low concentrations, but fail to do so with continual exposure to such concentrations.

CONCLUSION

The level of heavy metals used in this investigation was possibly higher than the normal ranges found in most of the oceans in the world. However, with the current trend of increasing levels of pollutants along the coast of Zanzibar Town due to domestic effluents, metal works, garages and petrol stations via land runoff, there is a possibility of higher concentrations of these metals occurring along the coastal areas in the near future. Indigestible organic compounds and some traces of heavy metals from landfills (garbage) can easily find their way into the ocean during rainfall due to surface runoff, potentially causing a serious problem to the creatures of the oceans. Although there is now knowledge of levels of toxicity of heavy metals on algae, there is a need to study the actual amount of heavy metals in waters along the coast of Zanzibar. This should lead to the development of laws and regulations aimed at controlling the discharge of untreated waste into the sea.

ACKNOWLEDGEMENTS

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Macroalgae as biofilters of dissolved inorganic nutrients in an integrated mariculture tank system in Zanzibar

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ABSTRACT

A laboratory experiment was conducted to determine the capacity of the macroalgae Eucheuma denticulatum, Gracilaria crassa and Ulva reticulata to remove dissolved inorganic nutrients from finfish effluents in serially arranged tank systems. The aim was to determine the capacity of macroalgae which could be used in an integrated mariculture pond system at Makoba, Zanzibar. Seawater from the reservoir entered the finfish tanks first, then drained through plastic pipes into the shellfish units and finally into the macroalgae units before being discharged back into the sea. The water residence time in each tank was 4 days. The performance of each of the different units was assessed in terms of total ammonia-N, phosphate-P and nitrate-N produced by finfish, and then, the removal of these nutrients by shellfish and macroalgae biofilters. The levels of dissolved inorganic nutrients were highest in the finfish units and lowest in the macroalgae units. Increase in stocking density of macroalgae from 1g/l to 2g/l was related to their increase in daily growth rates, specific growth rates and inorganic nutrient uptake rates. However optimum stocking densities were not reached. Of the three inorganic nutrients, ammonia-N and phosphate-P was taken up by the macroalgae much more than nitrate-N. Ammonia-N removal efficiency in the system reached a maximum of about 63% at 2g/l of Ulva reticulata whereas, phosphate-P and nitrate-N maximum removal capacity were 58 and 54% respectively. Among the three species of macroalgae, Ulva reticulata seems to be the most efficient biofilter. It is concluded that locally available macroalgae are good bioregulators of water quality, thus can be applied in small scale mariculture activities and can also generate income.

INTRODUCTION

Mariculture possesses great potential for protein production worldwide. However, the development of mariculture in Africa has experienced several failures including low
human capital which prevent people from going into fish farming due to low output per work day (Christensen, 1995). Land-based mariculture development has also caused environmental problems including salinisation of terrestrial environments, and pollution downstream originating from fish effluents when discharged without prior treatment. Fish grown in mariculture systems retain only 20 to 30% of the food supplied as body flesh (Porter et al., 1987; Hall et al., 1992). The remaining 70 to 80% is excreted in two major forms: (1) as dissolved nutrients, and (2) as particulate organic matter. Microbial degradation of leftover food, fish faeces and fish excretion has been reported to cause several pollution problems within the culture media and outside, such as reduction of oxygen content and algal blooms (Bell et al., 1989).

Previous studies have used phytoplankton to reduce excess dissolved inorganic nutrients from fish effluents (Gordin et al., 1981; Krom and Neori, 1989). However, the phytoplankton are subject to uncontrollable blooms that are likely to cause changes in water quality, particularly in terms of ammonia and dissolved oxygen (Krom et al., 1985).

Therefore the development of sustainable integrated mariculture is vital if we are to feed an ever-growing population with minimum damage to the environment. Ryther et al., 1975 suggested the use of seaweeds as biofilters for the first time. Following their work, several studies have reported that, submerged macroalgae such as Ulva lactuca can efficiently remove dissolved nutrients from fish effluents (Neori et al., 1991; Cohen and Neori, 1991; Vandermeulen and Gordin, 1990). Such seaweeds (macroalgae), cannot only remove dissolved inorganic nutrients, but they also produce a biomass which could be used in several ways (Kissil et al., 1992; Arieli et al., 1993; Neori et al., 1996; Haglund and Pedersen, 1993). In this study we proposed to investigate the performance of the macroalgae Eucheuma denticulatum (Rhodophyta), Gracilaria crassa (Rhodophyta) and Ulva reticulata (Chlorophyta) in removing ammonia-N, phosphate-P and nitrate-N in an integrated mariculture tank system. This was attempted through a culture of rabbitfish (Siganus sutor) in tanks connected to shellfish (Pinctada magartifera) and the macroalgae.

**MATERIALS AND METHODS**

The experiment was conducted in the green house at Mazizini from 5 December 1998 to 2 April 1999. Mazizini is situated on the western coast of Zanzibar, south of Zanzibar town (Figure 1).

**Experimental systems**

Two set ups were investigated. In the first Ulva reticulata and Gracilaria crassa were studied in a system comprising six 400 litre plastic tanks with a surface area of 1m² each and one 500-litre tank as a seawater reservoir. The six tanks were connected in two series of three tanks each. Each series had (1) a finfish tank (FF), (2) a shellfish tank (SF) and (3) a seaweed tank (SW) containing either Gracilaria crassa (GC) or Ulva
Figure 1. A map of Zanzibar showing areas of sample collection and site where laboratory experiments were conducted.
*reticulata* (UR). The tanks were arranged as follows; Reservoir — Finfish — Shellfish — Macroalgae. The first series consisted of FF¹, SF¹ and GC, while the second series consisted of FF², SF² and UR. In the first and second series conducted between 5 December 1998 to 4 February 1999, the GC and UR stocking densities were 1g/l (i.e. 1g fresh weight of macroalgae per litre of effluent). From 8 February 1999 to 16 March 1999 the stocking densities were 2g/l.

In the second set up *Eucheuma denticulatum* (ED) was studied in the third series from 1 February 1999 to 2 April 1999. In this series, four tanks, two of about 800 litres and two of 400 litres were used. The two 800 litre tanks were used for FF³ and SF³ and the two 400-litre tanks were stocked with 1g/l and 2g/l of ED respectively. The effluent from FF³ was discharged into SF³ systems, and from the latter, half of the effluents were discharged into a tank with an ED density of 1g/l and the remaining half was directed into a tank with an ED density of 2g/l. The superscripts 1, 2 and 3 above FF and SF refer to the first, second and third series of experiments. As in series 1 and 2, the reservoir (R) supplied seawater to FF³.

A control experiment was carried out to determine nutrient loss by physical and/or microbial processes. The effluents with known concentrations of inorganic nutrients were subjected to three aerated plastic buckets without macroalgae. The amount of nutrient lost was determined from samples collected concurrently from experimental setups in series 1, 2 and 3. The water retention time in each series was four days. Aeration of the experimental tanks was achieved using air pumps.

**Experimental materials**

*Macroalgae*

The macroalgae *Ulva reticulata*, *Gracilaria crassa* and *Eucheuma denticulatum* were collected from Kizingo beach, Chwaka Bay and Matemwe respectively. They were transported to the laboratory in 20-litre plastic containers filled with seawater.

*Finfish*

Fingerlings of *Siganus sutor* were collected along the shore near the Institute of Marine Sciences (IMS), Zanzibar. The collection was done using small beach seine net during low tide. The collected fingerlings were kept in aerated tanks at the IMS for two days before being transferred into 40-litre plastic buckets. Tanks FF¹ and FF² were stocked with 20 fingerlings with mean body weight of 5g and FF³ was stocked with 40 fingerlings. The finfish were fed twice a day at 0830 and 1830 hours, with 5% of their body weight. Their diet was made from a combination of *Ulva* sp. and sardines (1:1 w/w).

*Shellfish*

Individuals of the bivalve *Pinctada margaritifera* were collected from Unguja Ukuu situated on the west coast of Unguja Island. The animals were brought into the laboratory in 40-litre plastic buckets full of seawater. Tanks SF¹ and SF² were stocked with 2kg of shellfish regardless of the differences in shellfish body weight. 4kg of the shellfish were
stocked SF³. It was difficult to properly clean the shellfish tanks as this could disturb the shellfish attachment. As a result, opportunistic photosynthetically active flora particularly cyanobacteria (Lyngbya sp.) were found growing on the insides of the tanks.

Data collection and sampling
Temperature, light, salinity and pH were measured 3 times during the day, using a thermometer, light meter, hand-held refractometer and a pH meter respectively. The means of the three readings for each parameter were calculated.

Water samples for dissolved inorganic nutrient analysis were taken after every four days. The samples were filtered through a 25mm glass-fibre filter. 10 ml of water samples for ammonia-N and phosphate-P were taken in triplicate and duplicate respectively and stored in 20ml acid-washed vials. About 100ml were sampled for nitrate-N analysis. All samples except those for nitrate-N were analysed after a maximum of four days. Analysis was done as described in Parson’s et al. (1984).

Survival of finfish as percentage of the initial stock, body weight and length were determined monthly. The survival was determined using the formula below:

\[
\text{Survival (\%)} = \left( \frac{N_f}{N_i} \right) \times 100
\]

where \( N_i \) = number of fingerlings at stocking time, \( N_f \) = number of fingerlings during weighing time. Weighing balance and measuring board were used to estimate fish weight and length respectively. Half of the finfish were measured and their mean weight and length were recorded. Ectoparasites observed on the body of live and dead fish were collected and preserved in 5% formalin for subsequent identification. The finfish tanks were then restocked. 5% potassium permanganate solution was used to clean the tanks so as to eliminate ectoparasites.

Survival of shellfish as percentage of the initial stock (total weight) were determined using the following formula:

\[
\text{Survival (\%)} = \left( \frac{W_f}{W_i} \right) \times 100
\]

where \( W_i \) = initial weight during stocking time and \( W_f \) = final total weight at time of weighing.

Macroalgae wet weight was determined weekly using a weighing balance and returned to the tanks. Daily growth rate (DGR) was calculated using the formula below (Lignell et al., 1987):

\[
\text{DGR} = \left( \frac{W_f}{W_i} \right)^{t/\tau} - 1 \times 100
\]

where \( W_i \) and \( W_f \) are initial biomass and final biomass at day \( t \), respectively.

The dissolved inorganic nutrient uptake rates were determined as a loss of that nutrient in the culture medium using the formula below modified from Krom et al. (1985):
\[ V = (S_0 - S_1) \]  \hspace{2cm} (4)

where \( V \) = uptake rates (\( \mu g\text{-at.} l/\text{day} \)), \( S_0 \) = inflow nutrient concentration and \( S_1 \) = outflow nutrient concentrations.

**RESULTS**

**Physical and chemical factors**

The temperature ranged between 25°C in the morning to 27°C in the afternoon. A maximum mean irradiance of 32\( \mu \) photon \( m^2/s \) was recorded at the surface and 18\( \mu \)mol photon \( m^2/s \) was recorded at the bottom of the containers.

The salinity ranged between 35.6 and 36.2\%\text{o} in the reservoir and between 38.0 and 38.7\%\text{o} in macroalgae systems. pH values of 8.5 to 8.6 were measured in *Eucheuma denticulatum*. In *Ulva reticulata* the pH varied from 8.2 to 8.3 and pH values of 8.3 to 8.4 were recorded in *Gracilaria crassa* systems.

**Shellfish and finfish growth and survival**

The mean body weight of finfish (FF\(^1\), FF\(^2\) and FF\(^3\) ) ranged from 10.8–18.4g and their length ranged from 7.9–12.6cm. The weight and length of shellfish were not determined. The survival of shellfish and finfish were about 65 and 70\% respectively.

**Dissolved inorganic nutrient concentrations**

Figures 2a–2c, 3a–3c and 4a–4c show the mean concentrations of ammonia-N, phosphate-P and nitrate-N. The concentrations in the finfish effluents gradually decreased as the effluents flowed to the macroalgae tanks via the shellfish tanks at all stocking densities of macroalgae. In all units, the concentration of ammonia-N and phosphate-P were higher in the finfish tanks. The lowest concentrations were recorded in the macroalgae tanks. The minimum mean concentrations recorded in the macroalgae were 26.2 (36.5\%) \( \mu g\text{-at.} N/l \) for ammonia-N, 17.2 (41.7\%) \( \mu g\text{-at.} P/l \) for phosphate-P and 0.34 (44.4\%) \( \mu g\text{-at.} N_3/l \) of nitrate-N.

**Reduction and uptake rates of nutrients by shellfish and macroalgae**

The percentage of ammonia-N reduction reached a maximum of 63\% at 2g/l of *Ulva reticulata*. For phosphate-P, the maximum reduction was 58\% at 2g/l of *Ulva reticulata*. Maximum reduction of nitrate-N was 56\% at 2g/l of *Gracilaria crassa*. The reduction of dissolved inorganic nutrients in the control experiments were 0.5, 0.3 and 0.2\% for ammonia-N, phosphate-P and nitrate-N respectively. The uptake rates of dissolved ammonia-N, phosphate-P and nitrate-N by macroalgae were found to increase with increase in stocking densities. Higher uptake rates of 7.4\( \mu g\text{-at.} N/l/day \) for ammonia-N was recorded in *Ulva reticulata* at 2g/l followed by 7.0\( \mu g\text{-at.} N/l/day \) recorded in *E. denticulatum* at 2g/l. Phosphate-P taken at 2g/l of *U. reticulata* reached a rare value of up to 4.12\( \mu g\text{-at.} N/l/day \). The highest nitrate-N uptake rates of 0.11\( \mu g\text{-at.} N_3/l/day \)
Figure 2a. Mean concentration of ammonia-N from 5/12/98–16/3/99

Figure 2b. Mean concentration of phosphate-P from 5/12/98–12/3/99

Figure 2c. Mean concentration of nitrate-N from 5/12/98–12/3/99
R = reservoir, FF = finfish, SF = shellfish, SW = G. crassa and 1 = series number
Figure 3a. Mean concentration of ammonia-N from 12/8/98–16/3/99

Figure 3b. Mean concentration of phosphate-P from 8/12/98–12/3/99

Figure 3c. Mean concentration of nitrate-N from 5/12/98–12/3/99

R = reservoir, FF = finfish, SF = shellfish, SW = *U. reticulata* and 2 = series number
Figure 4a. Mean concentration of ammonia-N from 1/2/99–2/4/99

Figure 4b. Mean concentration of phosphate-P from 1/2/99–2/4/99

Figure 4c. Mean concentration of nitrate-N from 1/2/99–2/4/99
R = reservoir, FF = finfish, SF=shellfish, SW= E. denticulatum and 3 = series number
was recorded in *E. denticulatum* at 2g/l. The contribution of shellfish systems in both uptake rates and percentage reduction was probably due to the presence of cyanobacteria rather than to the shellfish themselves.

**Growth of macroalgae**

Table 1 shows the mean daily growth rate of *E. denticulatum*, *Ulva reticulata* and *G. crassa*. The mean daily growth rates (DGR) and dissolved inorganic nutrient uptake were found to be linked to the stocking densities. The maximum mean DGR was recorded in *U. reticulata* at a stocking density of 2g/l followed by *E. denticulatum* also at 2g/l, whereas, the minimum mean DGR was recorded in *G. crassa* at 2g/l. On some days there was a loss of wet weight of macroalgae, possibly due to fragmentation, bleaching and grazing by amphipods.

<table>
<thead>
<tr>
<th>Macroalgae species</th>
<th>DGR</th>
<th>DGR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1g/l</td>
<td>2g/l</td>
</tr>
<tr>
<td><em>Ulva reticulata</em> (SW⁴)</td>
<td>5.52</td>
<td>8.27</td>
</tr>
<tr>
<td><em>Eucheuma denticulatum</em> (SW⁴)</td>
<td>5.32</td>
<td>5.96</td>
</tr>
<tr>
<td><em>Gracilaria crassa</em> (SW⁴)</td>
<td>3.44</td>
<td>3.52</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The concentrations of dissolved inorganic nutrients recorded in the reservoir were very low compared to those recorded in the experimental tanks, and were thus neglected. The main source of dissolved inorganic nutrients into the system was from the food for the cultured fish. Food given to cultured fish can give rise to inorganic nutrients through fish metabolites and leftovers which could be degraded by microbial activities (Krom et al., 1989; Neori et al., 1989).

The low concentrations of inorganic nutrients observed in the macroalgae systems was possibly due to uptake by macroalgae. The intermediate concentrations in the shellfish tanks were probably due to uptake by microphytes especially cyanobacteria. It was difficult to properly clean the tanks with shellfish as this could disturb the shellfish attachment. As a result, opportunistic photosynthetically active flora such as *Lyngbya* sp. grew on the sides within the tanks.

The highest growth rates were recorded in *Ulva reticulata* followed by *Eucheuma denticulatum* and *Gracilaria crassa* at the same stocking densities. This may be attributed to high surface area of *Ulva reticulata*. The differences in the ratio of surface area to volume (S:V), may lead to differences in nutrient uptake rates among macroalgae (Rosenberg and Ramus, 1984; Cohen and Neori, 1991). Although the macroalgae were
grown at a low irradiance their high ability for photoacclimation (Vandermeulen, 1989) might have contributed to the high growth rate and nutrient uptake rates. It is also possible that light limitation had negative effects on growth rates and nutrient uptake rates.

The low percentage reduction of ammonia-N, phosphate-P and nitrate-N observed in the control experiments compared to those recorded in tanks with macroalgae show that the macroalgae biofilters are responsible for inorganic nutrient reduction in the systems.

The finfish mortality recorded during this study was probably due to infection by ectoparasites found on the body of live and dead fish. The mortality of shellfish was probably due to culturing conditions as they were completely immersed in the effluents most of the time except during effluent exchange. Such condition might have interfered with the normal rhythms of their physiological processes. In the marine environment, the shellfish are found in the intertidal areas where they are exposed during the low tide and submerged during the high tides almost twice per day. The survival of shellfish probably can be improved by allowing them to receive a splash of seawater as in the natural environment.

CONCLUSIONS

The macroalgae used in this study can efficiently remove dissolved inorganic nutrients from fish effluents, and their biofiltration capacities increased with increase in stocking density of macroalgae. Among the three species of macroalgae, *Ulva reticulata* showed the highest nutrient uptake rate and high growth rates. Thus, the results from this study can be applied in developing a small-scale wastewater treatment pond system.

ACKNOWLEDGEMENT

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REFERENCES


Nutrients levels and their dynamics in the coral reefs off Zanzibar Town

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ABSTRACT

Levels of ammonium, nitrate and soluble reactive phosphate (SRP) and their dynamics in two coral reefs close to Zanzibar town were measured over one year. The results showed that nutrient concentrations were above threshold limits for the healthy growth of corals. Patterns of nutrient concentrations during changes between wet and dry seasons were not statistically significant. Total inorganic nitrogen in the water column was 3.2 and 3.3μM at Chapwani and Bawe respectively, while SRP was 0.22μM at Chapwani and 0.20μM at Bawe. Ammonium concentration fluctuated significantly between neap tides and spring tides but not between stations. Concentrations of SRP and nitrate/nitrite did not show significant fluctuations either between sites or tides. Pore-water ammonium and SRP levels were high for both study sites, at 342 ± 68.4 and 690 ± 81.2μM ammonium and 35 ± 11.6 and 66 ± 26.2μM SRP for Chapwani and Bawe respectively. Nutrient fluxes measurement revealed that there is net movement of ammonium and SRP from the sediment into the water column while nitrate/nitrite moved from the water column into the sediment. Differences in ammonium and SRP concentration in the water column are influenced by water movements towards the reefs during flood tides and away from the reef during ebb tides. Higher nutrient concentrations in the sediment than in the water column create a concentration gradient and hence net fluxes of ammonium and SRP from the sediment into the water column. The flux of nitrate/nitrite into the sediment can be explained by assimilation of nitrate/nitrite by algae or transformation to ammonium at the water-sediment interface.

INTRODUCTION

Zanzibar town is located on the west coast of Unguja Island. The coast off Zanzibar town harbours scattered islets and sandbanks which fringe coral reefs and are subjected to different human activities. These include nutrient pollution (Mohammed et al., 1993), erosion and siltation (Msuya, 1997) and overexploitation (Muhando, 1997). Signs of
stress on corals around the town are obvious. Nutrient enrichment from the sewage effluent is thought to be the main cause (Johnstone and Suleiman, 1997; UNEP, 1989).

Dissolved nutrients in coral reef waters play an important role in overall productivity. High levels of nutrients produce a pronounced qualitative effect of the coral community (Birkeland, 1988). For example, a number of biochemical parameters are affected when coral reefs are exposed to elevated levels of nutrients (Larkum and Steven, 1994). These include changes in metabolism, density of the zooxanthellae and chlorophyll concentration per cell (Muscatine et al., 1989), decrease in skeleton density and misshaped aragonite structure (Strambler et al., 1991).

Bioerosion (a common destructive process in reefs) is also known to be enhanced by nutrient enrichment (Larkum and Steven, 1994). Experimental evidence strongly suggests that elevated nutrient concentrations, especially phosphates, can suppress coral reef calcification directly by more than 50% (Kinsey and Davies, 1979). In addition, benthic coralline algae, very significant coral reef builders, are also affected by high phosphate levels (Björk et al., 1995). Another indirect effect of nutrient enrichment is the shift in species composition of the community (Bell, 1992; Done, 1992), whereby larger, slow-growing organisms, surviving in nutrient-poor waters are replaced by smaller, rapidly growing species when the nutrient concentrations are raised (Birkeland, 1988). The enrichment also enhance algal activity (Kinsey and Davies, 1979), which overgrow and out-compete corals, and eventually dominate hard substratum rendering it unsuitable for coral growth (Larkum and Steven, 1994).

The distribution of inorganic nutrients in coral reefs is still uncertain and has not been adequately explained (Kinsey and Davies, 1979). Some workers suggest that coral reefs are distributed in waters with quite a wide range of phosphate levels (Reid, 1961) though nitrogen levels are generally rather low (Webb et al., 1975). In Pacific reef waters, reactive phosphate levels range from 0.15μM to 0.6μM (Pilson and Betzer, 1973). The ambient levels of ammonium range from 0.2 to 1.4μM NH₄⁺-N (Burris, 1983) and nitrate levels are always below 0.5μM NO₃⁻-N (Kinsey and Davies, 1979). In Chumbe Island, Zanzibar, nutrient concentration levels were found to be 0.2μg-at/l PO₄³⁻, 0.25μg-at/l NO₃⁻ while ammonium was below detection limits (Mohammed et al., 1993). However, higher levels of nutrients were observed in reefs near the town, with values ranging from 3.75 to 15.17μg-at/l PO₄³⁻, 26μg-at/l NH₄⁺ and 1.3 to 7μg-at/l NO₃⁻ (Mohammed et al., 1993).

Zanzibar marine waters are characterised by highly diverse coastal ecosystems such as mangrove swamps, coral reefs and seagrass beds. Rapid growth in the tourism and industrial sectors accompanied with rapid urban population increase of about 5% per annum (UNEP, 1989), are major threats to the coastal water quality. Raw sewage from Zanzibar town discharged into the sea has caused the nearby corals, e.g. at Chapwani Island, to be under continuous stress due to high turbidity levels, caused by planktonic and suspended organic materials (UNEP, 1989). Nutrient and sewage input leads to chronic stress in the ecosystem. Although corals are quite resistant to this type
of stress, ultimately it has a marked influence by preventing proper recovery of reefs when acute stress, such as crown-of-thorns starfish infestation, storms, etc. befall the reef community (Kinsey, 1988). Water quality around Zanzibar town is subjected to high domestic and industrial sewage pollution (Mohammed et al., 1993). If immediate measures are not taken, the reefs may suffer destruction in the near future.

Apart from the work by Mohammed et al. (1993) on the effects of pollution on the reefs and Björk et al. (1995) on coralline algae threatened by pollution, no intensive studies (in water column and pore-water) have been carried out to assess the natural nutrient levels in Zanzibar coral reefs and the enrichment levels caused by the existing sources of pollution. The present study was expected to reveal the ambient levels of nutrients in the reefs and the levels caused by the raw sewage input.

The specific objectives of this study were to:

1. Determine the concentration of nitrate, ammonium and phosphate in the water column in polluted and non-polluted sites.
2. Determine the concentration of ammonium and phosphate in the sediment pore-water in polluted and non-polluted sites.
3. Determine fluctuations of nutrients between tidal cycles and seasons.

Study sites

Chapwani and Bawe represent a gradient of exposure to nutrients from the untreated sewage of the Zanzibar municipality (Björk et al., 1995). Chapwani, the closest site to the central sewage outlet, is considered to be the most polluted reef, while Bawe is far from the outlet (Zanzibar town) and hence less polluted (Figure 1).

Chapwani Island is located between 6° 07’ S and 39° 11’ E, about 2 nautical miles north of Zanzibar town. It is surrounded by an extensive growth of seagrass bed. The island has a poorly developed patch reef cover of not more than 20% (UNEP, 1989). Bwawani Hotel and the port of Zanzibar have been described as the major sources of municipal pollutants (Mohammed et al., 1993). The direction of water current is such that it carries sewage waste away from these areas to the island (Mohammed et al., 1993). The water around this island has been described as having high turbidity level which is attributed to planktonic and suspended organic material from the raw sewage effluent (UNEP, 1989).

Bawe Island is located between 6° 08’ S and 39° 08’ E, about 6km west of Zanzibar town, and is covered with dense shrub vegetation. Seagrass cover is relatively poorly developed compared to Chapwani. There is well developed loosely aggregated patch reef on the northeast and southeast of the island. There is a strong current crossing the island on its eastern side, possibly making a barrier between the island and Zanzibar Town.

Climate and hydrography

Zanzibar islands, like the whole of East Africa, are under the influence of monsoon winds, with southeast monsoon blowing between April and October, and northeast
Figure 1. Map of Unguja Island showing the location of Chapwani and Bawe Islands
monsoon between November and March. Generally, the winds are strong during the southeast monsoon reaching a maximum 4.5 knots and calmer during northeast monsoon with maximum speed of 2 knots (Newell, 1959). The East African coastal current is permanently northbound, and its strength depends largely on the direction of the monsoon winds (Newell, 1959). The nearshore water currents are greatly influenced by tidal cycle, with flood tidal currents flowing from the open sea towards the islands (Chapwani, Changuu and Bawe) and ebb tide currents in the reverse direction (Mwaipopo, 1990).

The presence of passages and platforms between the islands has great influence on the tidal currents on the west coast of Zanzibar town (Shaghude and Wannas, 1998).

MATERIALS AND METHODS

Seawater and porewater sampling
Seawater samples were collected at 0.5m below the surface at coral reef areas. Sampling was done on three consecutive days, during both neap and spring tides. Each site was sampled twice a month during neap and spring tides from June 1996 to July 1997. Samples were filtered in the field using a 60ml syringe with a glass microfibre filter (GF/C). The filtered seawater (10ml) was stored in plastic vials which were previously soaked in 10% HCl and rinsed three times with distilled de-ionised water (DDW). After filtration, the samples were immediately placed under ice. In the laboratory, the samples were kept frozen until analysis (for ammonium and SRP) within a fortnight. Samples for ammonium and soluble reactive phosphate (SRP) were analysed by the Indophenol method and complex formation between SRP, molybdic acid, ascorbic acid and trivalent antimonyl respectively (UNESCO, 1983; Parsons et al., 1989). Water samples for nitrate/nitrite were run through an autoanlyser (Parsons et al., 1989).

Pore water sampling and analysis
Plastic sample corers (5cm diameter and >5cm long) were used to take sediment on sand patches close to the benthic chamber experiments (see determination of nutrient fluxes). The plastic corers were pushed into the substrate to the required depth in the sediment. Sub-samples of the top 5-cm-thick sections were taken from each core. The portion was centrifuged for 10 minutes where 3000rpm were used to get the porewater from the sediment. Porewater was then filtered through a glass microfibre filter and stored at -20°C until analysis. Analyses of the sediment samples were carried out within a period of 2 months.

Determination of nutrient fluxes
Nutrient fluxes were determined following the method described by Johnstone et al. (1988), Johnstone (1989) and Johnstone and Olafsson (1995). In situ benthic chambers which were tightly fixed over the sediment around the coral reef were used. A chamber
consisted of a circular base made of aluminium sheet and a polycarbonate dome (Figure 2).

The base (the skirt) acted as an anchorage platform for the dome as well as a barrier to lateral water movement from sediment outside the dome area. When placing the chambers the base was pushed into the sediment to at least half of the base height. The upper rim of the base provides a flat surface for attachment with the dome. The smooth surface on the base and a rubber gasket on the dome provide perfect sealing. The dome was fastened to the base by elastic rubber bands secured on hooks from the base and the dome. The domes were mounted with a battery-driven pump which served to mix the water throughout the experiment. On the sides of the domes were holes plugged with self-sealing rubber corks (sampling ports).

![Diagram](image)

Figure 2. Benthic chamber used for benthic community production and nutrient fluxes experiments

Sample from the dome was withdrawn by inserting two needles into the dome through the rubber corks. A syringe was mounted on one of the needles, through which sample was drawn from the dome. The other needle was used to allow water to pass into the domes, replacing the sampled water and avoiding intrusion of water from the sediment into the chambers. Water within the dome was sampled at intervals of 2 hours. Three sampling days were conducted on each site.
Statistical analysis
Differences in nutrient concentration and fluctuations of nutrients between seasons and tidal cycles in the water column were determined by single factor analysis of variance. Tukey test was used to determine significant differences among the means. Nutrient concentrations in the sediment and the nutrient fluxes were determined by Mann-Whitney U-test.

RESULTS
Ammonium concentrations in the water column during neap tides and spring tides were significantly different (Single factor ANOVA, $F = 33.53$, $p < 5 \times 10^{-8}$, d.f. = 20). However, the difference was only between neap and spring tides at both sites and not within the sites (Table 1). Higher concentrations were found on neap tides and lower on spring tides. On the other hand, there was no significant difference in SRP concentration between the sites and tides (Single factor ANOVA, $F = 0.473$, $p > 0.7$, d.f. = 20).

The highest level of 3.2 μg.atoms NO$_3^-$/NO$_2^-$ N/dm$^3$ and the lowest of 2.3 μg.atoms NO$_3^-$/NO$_2^-$ N/dm$^3$ were measured at Bawe during neap tides and spring tides respectively. At Chapwani, tidal changes did not show any influence over the nitrate/nitrite concentrations, as similar values were measured (2.6 μg.atoms NO$_3^-$/NO$_2^-$ N/dm$^3$ for both neap and spring tides) in the water column. The variations of nitrate/nitrite concentration on the study sites are statistically not different (Single factor ANOVA, $F = 1.1$ $p > 0.4$, d.f. = 24).

Analysis of nutrient concentrations during dry and wet seasons showed that the nutrient levels do not fluctuate with season. Statistical analysis on ammonium and SRP levels between the dry spells, short rains and long rains, showed no significant difference between the study sites (Single factor ANOVA, $F = 0.11$ $p > 1$, d.f. = 18 for ammonium) and (Single factor ANOVA, $F = 1.04$ $p < 0.4$, d.f. = 18 for SRP)

Nutrient concentrations in the sediment were far higher than those in the water column (Table 2). The levels of ammonium and SRP at Bawe are about twice those at

Table 1. Nutrient concentrations in the water column in Zanzibar at different seasons and tides

<table>
<thead>
<tr>
<th>Time</th>
<th>Ammonium μg at./l</th>
<th>Phosphate μg at./l</th>
<th>Nitrate/nitrite μg at./l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chapwani</td>
<td>Bawe</td>
<td>Chapwani</td>
</tr>
<tr>
<td>Nov-Dec short rains</td>
<td>0.53</td>
<td>0.61</td>
<td>0.22</td>
</tr>
<tr>
<td>Mar-Jun long rains</td>
<td>0.62</td>
<td>0.56</td>
<td>0.17</td>
</tr>
<tr>
<td>Jan-Feb Jul-Oct</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry season</td>
<td>0.61</td>
<td>0.67</td>
<td>0.23</td>
</tr>
<tr>
<td>Spring tides</td>
<td>0.47</td>
<td>0.44</td>
<td>0.23</td>
</tr>
<tr>
<td>Neap tides</td>
<td>0.74</td>
<td>0.76</td>
<td>0.23</td>
</tr>
</tbody>
</table>

- = no data.
Chapwani. There was a statistically significant difference in concentrations of both ammonium (Mann-Whitney U = 0.00, p < 0.05, n₁=n₂ = 3) and SRP (Mann-Whitney U-test, U = 2, p < 0.05, n₁=n₂ = 3) at Chapwani and Bawe. Nitrate/nitrite concentration in the pore-water was higher at both sites, with Bawe being much higher (6.6\(\mu\)g.atoms NO\(_3^-\)/NO\(_2^-\) N/dm\(^3\)) than Chapwani (4.7\(\mu\)g.atoms NO\(_3^-\)/NO\(_2^-\) N/dm\(^3\)). However, the difference is not statistically significant (U = 7, p < 0.05, n₁=n₂ = 3, Mann-Whitney U-test).

<table>
<thead>
<tr>
<th>Site</th>
<th>Ammonium (\mu g) at./l</th>
<th>SRP (\mu g) at./l</th>
<th>Nitrate/nitrite (\mu g) at./l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapwani</td>
<td>342</td>
<td>35</td>
<td>4.7</td>
</tr>
<tr>
<td>Bawe</td>
<td>690</td>
<td>66</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Ammonium, nitrate/nitrite and SRP fluxes between sediment and water column were measured in situ. There was a net flow from the sediment into the overlying water of ammonium and SRP (efflux), while for nitrate/nitrite, the fluxes were from the water column into the sediment (influx). In each nutrient, the trend for the fluxes were the same for both sites.

The rates for ammonium fluxes were 19.63\(\mu\)g atoms NH\(_4^+\) N/m\(^2\)/h and 6.81\(\mu\)g atoms NH\(_4^+\) N/m\(^2\)/h for Bawe and Chapwani respectively. The fluxes for SRP were 1.14 \(\mu\)g atoms PO\(_4^{3-}\)P/m\(^2\)/h for Chapwani and 0.32\(\mu\)g. atoms PO\(_4^{3-}\)P/m\(^2\)/h for Bawe. Flux rates of 22.88\(\mu\)g. atoms NO\(_3^-\)/ NO\(_2^-\) N/m\(^2\)/h were measured at Chapwani compared to 16.06\(\mu\)g. atoms NO\(_3^-\)/ NO\(_2^-\) N/m\(^2\)/h at Bawe. However, the difference was statistically non significant for ammonium (U = 49.0, p > 0.05 n₁=n₂ = 4, Mann-Whitney U-test), SRP (U = 50.5, p > 0.05, n₁=n₂ = 4, Mann-Whitney U-test) and nitrate/nitrite (U = 84.5, p < 0.05, n₁=n₂ = 4, Mann-Whitney U-test).

**DISCUSSION**

This study has revealed that the mean water column concentration of soluble reactive phosphate (SRP) is similar for Chapwani and Bawe during the dry and wet seasons, as well as during both neap and spring tides. The results have shown that there are statistical similarities in SRP concentrations in all tidal levels and sites. However, SRP levels are slightly higher at Chapwani compared to Bawe. Since a possible source or cause of elevated phosphate levels could be sewage discharge, then it can be hypothesised that phosphate from the sewage outfall is transported to a great distance. This study is in agreement with Björk et al. (1995), that SRP is transported before being assimilated and incorporated into cellular tissues of phytoplankton and some macroalgae. Since the regeneration of benthic organic matter affects water column nutrient concentration (Valiela, 1984), the higher level of SRP in the pore water of these two sites has possibly influenced the elevated SRP
levels in the water column. This is also supported by the flux of SRP from the sediment into the overlying water. However, higher SRP levels at Chapwani as compared to Bawe, indicate that sewage waste is more responsible for the higher phosphate level at Chapwani than efflux.

The phosphate level at Chapwani is higher during low tides than during high tides, especially at spring low and high tides, (Mohammed, 2000) as a result of the dilution effect from incoming oceanic water. During ebb tide the water flows away from the site (Mwaipopo, 1990) and flushes the nutrients. Low water (during low tides) becomes mixed with sewage waste and high efflux rate of SRP from the sediment (1.14µg. atoms P/m²/h) enriches again the overlying water at Chapwani. The condition at Bawe is different since the central sewage outlet is far from this site. The contribution from the sewage can be very low, and the low efflux rate from the sediment (0.32µg. atoms P/m²/h) can be the cause of the observed low SRP in the water column relative to Chapwani. In addition, the SRP consumption by the phytoplankton at Bawe is higher, thus increasing the removal of SRP, while at Chapwani low phytoplankton biomass (Table 3) reduces the consumption of SRP at Chapwani and hence increases the SRP concentration at this site.

Mean pore-water SRP concentration at Bawe is double that at Chapwani. This is contrary to what has been hypothesised on nutrient levels on these study sites (polluted and non-polluted). It was believed that higher concentration of SRP would be found at Chapwani. Also the higher pore water SRP concentrations, do not correspond with water column concentration which is relatively very low. These observations indicate that the SRP might be locked in the sediment and cannot be released into the water column.

Mean ammonium concentration between tides is different, being higher on neap tides and lower on spring tides. As it has been discussed earlier for SRP on the dilution effect, the same applies for ammonium. However, the difference in concentration (low on spring tides and high on neap tides) is due to input from the sediment. High efflux rates, 19.63 and 6.8µg. atoms NH₄⁺-N/m²/h for Bawe and Chapwani respectively can be the cause of the observed difference. On the contrary, Mohammed et al. (1993) and Björk et al. (1995) have reported higher ammonium levels at Chapwani than at Bawe.

Table 3. Nutrients and chlorophyll 'a' concentration in coral reefs that are considered eutrophic compared with the reefs off Zanzibar town

<table>
<thead>
<tr>
<th>Site</th>
<th>TIN</th>
<th>Phosphate</th>
<th>Chlorophyll 'a'</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canton Atoll</td>
<td>-</td>
<td>0.6µM</td>
<td>-</td>
<td>Kinsey and Davies (1979)</td>
</tr>
<tr>
<td>Kaneohe Bay</td>
<td>1.1µM</td>
<td>0.23µM</td>
<td>0.68mg/m³</td>
<td>Smith et al. (1981)</td>
</tr>
<tr>
<td>Barbados</td>
<td>1.0µM</td>
<td>0.06–0.08µM</td>
<td>0.4–0.6mg/m³</td>
<td>Tomascik and Sander (1985)</td>
</tr>
<tr>
<td>Kaneohe Bay</td>
<td>1.97µM</td>
<td>0.2µM</td>
<td>0.61mg/m³</td>
<td>Laws and Radalje (1979)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cited in Bell (1992)</td>
</tr>
<tr>
<td>Chapwani</td>
<td>3.2µM</td>
<td>0.22µM</td>
<td>0.81mg/m³</td>
<td>Mohammed (2000)</td>
</tr>
<tr>
<td>Bawe</td>
<td>3.3µM</td>
<td>0.20µM</td>
<td>0.90mg/m³</td>
<td>Mohammed (2000)</td>
</tr>
</tbody>
</table>

TIN = total inorganic nitrogen.
Measurements of nutrient fluxes show that there are net fluxes of ammonium and SRP from the sediment into the overlying water at both experimental sites. However, nitrate/nitrite levels show a reversed trend, i.e. flux from the water column into the sediment. There exists a relationship between ammonium concentration in the pore-water and the rate of fluxes. The higher sediment ammonium concentration at Bawe is accompanied by higher flux rate. At Chapwani, the sediment ammonium concentration is lower, and this is followed by lower flux rate. Nevertheless, the observed flux rates do not correspond to the concentration in the pore-water. For example, ammonium concentration at Bawe is twice that at Chapwani, but flux rates at Bawe are 3 times those at Chapwani. Charpy-Roubaud and Charpy (1994) have shown that fluxes of nutrients are higher in anoxic than in oxic conditions. By comparison, Bawe has lower oxygen level than Chapwani (Mohammed, 2000), a condition that can explain the observed fluxes of ammonium and SRP. In addition to that, concentration gradient between the sediment and the water column plays a great role for the magnitude of the flux.

The influx rate for nitrate/nitrite is higher at Chapwani than at Bawe, but does not correspond to the relative concentrations in the pore-waters, where besides the higher influx rates, the concentration in the pore-waters is lower at Chapwani. There is lower influx rate at Bawe but higher pore-water concentration. Higher influx rates of nitrate/nitrite and lower concentration in the pore-water can be explained by microbial metabolism as follows: (i) nitrate/nitrite is immediately utilised by primary producers at the sediment/water interface, (ii) nitrate/nitrite is transformed to ammonium by bacteria on the sediment surface. If this transformation takes place immediately on the sediment surface, then we can assume that the regenerated ammonium contributes to the elevated ammonium concentration in the water column. In addition to the above process, nitrate can be reduced to nitrogen gas (nitrification). This process requires anoxic conditions and in this experiment, oxygen level below 5mg/l (in the water close to the sea bottom) was not recorded. However, field observation during coring of sediment at Chapwani showed a black band at about the 3–4cm-deep marking the anoxic environment. This condition was not seen at Bawe. These observations can probably explain the observed results of higher influx rates of nitrate/nitrite which is used for nitrification in the sediment. If nitrate/nitrite from the water column ends up as nitrogen gas, it will not be detected in the pore-water.

Fluxes of SRP at the study sites are not related to pore-water concentration—the higher pore-water concentration of SRP at Bawe is accompanied with lower flux rates. A higher flux rate is found at Chapwani where there is relatively lower pore-water concentration. The anoxic condition of sediment at Chapwani relative to Bawe can be a significant factor in making phosphate salts more soluble at Chapwani, thus facilitating diffusion from the sediment to the overlying water. The more oxidised sediment (field observations) at Bawe can be a factor which makes phosphate salts bind to the sediment as hydroxides and make its flux much more difficult. It has been observed elsewhere that phosphate fluxes are related to anoxic conditions (Charpy-Roubaud and Charpy, 1994).
This study has revealed that the waters off Zanzibar town have elevated nutrient concentrations. The levels observed are above threshold limits for eutrophication in coral reefs as has been observed at other places (Table 3).

The levels of parameters shown in Table 3 have had adverse effects on the coral community structures of the named localities. For example, the coral community that existed in one part of the Kaneohe Bay (southeast) was considered to be the finest in the world (Bell, 1992). Sewage effluent discharged into the bay destroyed and replaced the existing coral community with benthic algae and filter feeders (Bell, 1992). In Barbados, the degree of eutrophication was less compared to that of Kaneohe Bay, resulting in a reduction of coral growth rate and settlement along the eutrophication gradient (Bell, 1992).

The cited examples, however, represent calmer, closed seas. In open waters where good flushing and high turbulence exists, threshold limits for coral reef eutrophication might be higher. Reefs around Zanzibar town are situated 3–5km off the main Island and are therefore well flushed. The chlorophyll ‘a’, phosphate and total inorganic nitrogen (TIN) at Chapwani and Bawe are far above the threshold limits for closed seas (Table 3).

It is suggested that threshold level for open seas is higher than that cited above. The reefs selected in this study are already subjected to higher levels of nutrients than reefs in areas with weaker flushing times, such as in lagoons (e.g. Kaneohe Bay and Barbados). If that is the case, then the reefs in Zanzibar are under threat of being destroyed and replaced by other faster-growing benthic communities, like filter feeders and benthic algae (see Done, 1992). Indeed, signs of this are already evident, e.g. the spread of a soft coral Rhodactis spp. (B. Kuguru, pers. commun. 1999).

REFERENCES


The effect of copper on the daily growth rate and photosynthetic efficiency of the brown macroalga *Padina boergesenii*

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ABSTRACT

The effect of copper (Cu) on the daily growth rate (DGR) and photosynthetic efficiency (PE) of the brown macroalga *Padina boergesenii* was studied under controlled laboratory conditions. The DGR was measured as an increase in fresh weight while the PE was measured as the ratio of variable to maximal chlorophyll fluorescence (Fv/Fm). *Padina boergesenii* were exposed to 25, 50, 100 and 500μg Cu/l for 21 days. The DGR and PE of *P. boergesenii* decreased significantly with an increase in copper concentration in the growth media. This study shows that copper is acutely toxic to *P. boergesenii* at concentrations higher than 500μg Cu/l. Low concentration of copper is toxic to *P. boergesenii* after a prolonged exposure of 21 days. Similarly, exposure time has a significant negative effect on both DGR and PE.

INTRODUCTION

The effect of heavy metals on aquatic organisms is currently attracting wide attention, particularly in studies related to industrial and anthropogenic pollution. The enrichment of coastal waters with trace metals through sewage and other anthropogenic sources has become a severe problem. This situation has resulted in numerous studies of the effects of heavy metals on benthic marine algae, especially in coastal areas (e.g. Strömgren, 1979a,b, 1980; Markham et al., 1980; Filho et al., 1996). Accumulation of heavy metals in marine environments has been extensively studied using marine macroalgae due to their ability to concentrate and tolerate high metal levels. Marine macroalgae have been shown to be good bioindicators of heavy metal contamination in seawater (Bryan, 1983; Soderlund et al., 1988). There has recently been an increase in the use of marine algae as test organisms in laboratory studies of marine pollution (Fletcher, 1991). Most of these experimental studies under controlled conditions have been conducted on species from temperate regions (Markham et al., 1980; Anderson and Hunt, 1988; Pellegrini et al., 1993) and data on tropical species is limited.
The use of copper in antifouling paints, in the treatment of diseases of fishes, in agricultural chemicals, and as algacides has increased the need to study the effects of this metal on aquatic organisms (Clark, 1986). The most extensive research on the effects of copper has been directed to fishes, because of their economic value, and few studies exist on the effect of copper on macroalgae.

MATERIALS AND METHODS

Study site
The brown macroalgae Padina boergesenii used in this experiment were collected at Bawe Island, 6km west of Zanzibar town. Water currents from the coastal area of Zanzibar town flows in a northerly direction and this may therefore prevent pollutants from reaching Bawe Island. Experimental work was conducted at the Institute of Marine Sciences, Zanzibar.

Experimental setup
The experiments were conducted indoors. All glassware used during the experiment was washed and soaked overnight in 1N HNO₃, then soaked overnight in de-ionised water. Seaweeds were cultivated in natural filtered seawater that was changed twice a week. Algae with known weight (about 4g/l) were cultivated in 2-litre glass beakers. Fluorescent tubes were used to provide extra light. Algae were acclimatised for 24 hours before heavy metal exposure. Each flask was aerated with ambient air to provide water movement. The culturing vessels were covered with a cellulose membrane in order to avoid extended evaporation and entrance of foreign particles. Temperature, pH and salinity was measured using a thermometer; a pH meter and refractometer respectively.

Toxicity of copper was tested using six replicates, with each set-up having a corresponding control. Each set-up had a control with no copper, 25, 50, 100 and 500 μg Cu/l. During selection of suitable exposure concentrations before the start of the experiments algae were subjected to higher concentrations of copper (1000μg Cu/l), but all the algal thalli died after a few days of exposure. During days 4, 7, 14 and 21 the photosynthetic efficiencies and daily growth rates of experimental algae were measured.

Determination of daily growth rate (DGR) of Padina boergesenii
The algae were carefully removed from the flasks using a piece of soft plastic-lined forceps and the excess water was blotted on filter paper. The macroalgal DGRs were expressed as a percentage increase in fresh weight and were calculated according to the equation DGR = 100[(W/W₀)ⁿ−1] (Lignell et al., 1987; Huglend et al., 1996) where W₀ is the initial biomass and Wₙ is the biomass at day t. The DGR was expressed as the percentage of the growth rate recorded from control algae.
Determination of photosynthetic efficiency (PE)
The ratio of variable chlorophyll fluorescence ($F_v$) to maximal chlorophyll fluorescence ($F_m$) is proportional to the quantum yield of photochemistry and gives an indication of the efficiency of the photosynthetic apparatus of macroalgae (Mtolera, 1996). The higher the value of $F_v/F_m$, the higher the photosynthetic efficiency. A reduction in $F_v/F_m$ indicates a decreased efficiency of the Photo system II (PS II). Such a situation may be induced by several factors including herbicides and pollutants, such as heavy metals like copper.

In this study PE was measured on algae exposed to heavy metals using the Hanstech’s Plant Efficiency Analyser (PEA) (Great Britain) after 4, 7, 14 and 21 days. A piece of the alga thallus was attached on the leaf holder of the Plant Efficiency Analyser equipment and subjected to dark conditions for about 10 minutes. Thereafter its fluorescence characteristics were measured. This was repeated six times for each treatment concentration.

Statistical tests
A factorial design (two way ANOVA with replication) according to Zar (1984) was used to test whether there were any significant effects of copper concentration and days of exposure on the DGR and PE of *P. boergesenii*. It was also used to test if concentration of copper had an interaction with days of exposure in affecting the DGR and PE of *P. boergesenii*.

RESULTS
Salinity, pH and temperature ranged from 35–37‰, 7.97–8.34 and 25–27°C respectively.

Daily growth rate (DGR) of *Padina boergesenii* exposed to copper
Daily growth rates as percentage per day results are presented in Figure 1. Generally the DGRs decreased significantly ($F_{(4, 40)}$=28.73; $p<0.000$) with an increase in copper concentration in the growth media. As number of days of exposure increased the inhibition in DGR also increased significantly ($F_{(3, 120)}$=60.83; $p<0.000$). There was also a significant interaction ($F_{(12, 120)}$=3.82, $p<0.001$) between copper concentration and algal exposure time in decreasing the DGR of *P. boergesenii*.

Table 1 shows the statistical results of comparisons of mean daily growth rates (DGRs) of different concentrations. The highest mean DGR occurred during day 4 for algal thalli that were exposed to 25μg Cu/l, which corresponds to a growth rate of 119.3±19.2% of the control. The lowest daily growth rate occurred after 21 days of exposure to 500μg/l of copper corresponding to 23.4±0.7% of control. For algal thalli exposed to 500μg/l of copper the DGR was highly inhibited.

Other changes were observed at 100 and 500μg Cu/l, where the culturing media turned light yellow from colourless. Thalli treated with 500μg Cu/l started to shed their
Figure 1. Daily growth rate of *Padina boergesenii* exposed to different concentrations of copper for 21 days.

### Table 1. Results of (SNK/Tukey) multiple comparison test for similarity of means for PE and DGR of *Padina boergesenii* between different concentrations of copper

<table>
<thead>
<tr>
<th>Concentration (μg Cu/l)</th>
<th>Control</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean PE</td>
<td>0.750</td>
<td>0.713</td>
<td>0.670</td>
<td>0.603</td>
<td>0.429</td>
</tr>
<tr>
<td>Mean DGR</td>
<td>0.892</td>
<td>0.922</td>
<td>0.553</td>
<td>0.361</td>
<td>-0.127</td>
</tr>
<tr>
<td>Control PE</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Control DGR</td>
<td>**</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>25 PE</td>
<td></td>
<td></td>
<td>n.s.</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>25 DGR</td>
<td></td>
<td></td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>50 PE</td>
<td></td>
<td></td>
<td></td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>50 DGR</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>100 PE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
</tr>
<tr>
<td>100 DGR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>***</td>
</tr>
<tr>
<td>500 PE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 DGR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n.s. = non significant; *=significant p<0.01; **=highly significant at p<0.001; ***=very highly significant at p<0.0001.

In addition, the thin outer layer of the thallus started to wear off at the start of the third week of exposure.
Photosynthetic efficiency (PE) of copper-exposed *Padina boergesenii*

Results of the effect of copper on the PE of *P. boergesenii* are presented as the mean values of Fv/Fm in Figure 2. It was observed that both concentration and exposure time had a significant (F(4, 40) = 28.73; p < 0.000 and F(3, 120) = 62.85; p < 0.000 respectively) effect in inhibiting the photosynthetic efficiency. There was also a significant interaction (F(12, 120) = 6.01; p < 0.000) between copper concentration and exposure time in inhibiting the photosynthetic efficiency of *P. boergesenii*. The mean PE for the controls was markedly stable throughout the experiment. In the presence of 25μg/l copper during day four the mean PE was the highest, equivalent to 105.0±1.5% of the control.

Table 1 also shows the results of statistical comparison test of mean PE between different treatments (concentrations) of copper. The lowest photosynthetic efficiencies were recorded in plants that were exposed to 500μg/l of copper (Figure 2) equivalent to 46.5±2.1% of the control. Nevertheless the mean photosynthetic efficiencies of every treatment (exposure concentrations) were significantly different from each other, (p < 0.05).

![Graph showing photosynthetic efficiency of *Padina boergesenii* exposed to different concentrations of copper for 21 days](image)

**Figure 2.** Photosynthetic efficiency of *Padina boergesenii* exposed to different concentrations of copper for 21 days

**DISCUSSION**

This study shows that the daily growth rate and photosynthetic efficiency of copper were reduced with an increase in copper concentration in the growth media (Figure 1 and 2). Similarly, the DGR and PE decreased with increase in exposure time (Figure 1
and 2). Probably accumulation of copper, which was taken up by the algal tissue, was responsible for the observed inhibition of both DGR and PE.

Concentration of copper in the growth media was directly proportional to the inhibition of DGR and PE of *P. boergeseni*. The mechanism of copper toxicity in this experiment was not studied, but Stauben and Florence (1987) pointed out that copper may interfere with cell permeability or the binding of essential metals. Following copper transport into the cytosol, copper may react with SH enzyme groups and free thiols (e.g. glutathione), disrupting enzyme active sites and cell division hence reducing growth. Copper may also exert its toxicity in subcellular organelles, interfering with mitochondrial electron transport, respiration, ATP production and photosynthesis in the chloroplasts. Copper ions are also likely to be transported to chloroplasts via cytoplasm where it inhibits photosynthesis by uncoupling electron transport to NADP⁺. Sorentino (1979) again mentioned that when ionic concentration increases, copper is bound to chloroplast membranes and other cell proteins, causing degradation of chlorophyll and other pigments. At higher concentrations copper produces irreversible damage to chloroplast lamellae preventing photosynthesis and may eventually cause plant death. Copper ions are also known to affect the permeability of the plasmalemma, which results in the loss of potassium ions from the cell (McBrien and Hassall, 1967; O'Kelly, 1974).

The highest daily growth rate and photosynthetic efficiency were expected to occur in controls, as no copper was added. However, it was observed that algae that were subjected to low concentrations of copper (25μg Cu/l) exhibited higher daily growth rate and photosynthetic efficiency than those of the control group, especially during the first earlier 4 days of exposure (Figure 1 and 2). Copper acts as a micronutrient when present at low concentrations (Sorentino, 1979) enhancing the growth of the algae. Brand et al. (1986) and Verweij et al. (1992) observed better growth of phytoplankton in the presence of low copper concentrations. It has also been observed by Strömgren (1979a) that the brown alga, *Ascophyllum nodosum* was unaffected by copper at concentrations of 33μg/l or less for 11 days of exposure.

Differing copper concentrations have been shown to affect growth and photosynthesis process. For example, at 28.58μg/l of copper the growth of the cyanophyte *Lyngbya nigra* was inhibited, however photosynthesis and respiration were inhibited severely at 44.8μg/l of copper (Gupta and Arora, 1978). This situation may explain what has been observed in this experiment, whereby growth rate was more inhibited compared to photosynthetic efficiency.

The observed colour change of the growth media at higher concentrations of copper might be due to loss of some pigments by the algae. A similar phenomenon has been reported by Gross et al. (1970) to occur in a fresh water green alga *Chlorella*. He observed the loss of photosynthetic colour pigments by this alga when exposed to excessive concentration of copper. Markham et al. (1980) reported significant loss of pigments from *Asteriolla formosa* when cadmium was added to the media. No other specific study has been done using *Padina boergesenii* to support the observed results.
CONCLUSION

Copper is acutely toxic to the macroalga *Padina boergesenii* at high concentrations, affecting both algal growth and photosynthesis. When *P. boergesenii* is exposed to low concentrations of copper for a long time it may exhibit toxic effects, hence inhibiting photosynthetic activity and growth. At very low concentration copper acts as a micro-nutrient, favouring some physiological activities of the algae. It is concluded that the degree of toxicity depends on both the concentration and exposure time.

ACKNOWLEDGEMENT

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Organochlorine pesticide residues in waters from the coastal area of Dar es Salaam and their effect on aquatic biota

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ABSTRACT

Water samples were collected from Msimbazi and Kizinga rivers in Dar es Salaam and from the coastal marine environment receiving waters from these rivers during both the wet season and the dry season and analysed for various organochlorine pesticide residues using GC-ECD. The pesticides pp'-'DDE, pp'-'DDT, dieldrin and γ-HCH were the only organochlorines detected at significantly greater concentrations above detection limits. There was a marked difference on the frequency of pesticide residue detection during the two seasons. All the wet season samples and 37.5% of the dry season samples contained pp'-'DDE at concentrations ranging from 0.05 to 0.45µg/l and 0.08 to 0.20µg/l respectively. pp'-'DDT was detected in 25% of the dry season samples at a concentration range of 0.1–0.4µg/l and in 81% of the wet season samples at concentrations ranging from 0.1– 0.3µg/l. Dieldrin and γ-HCH were only detected during the wet season. Dieldrin amounts ranging between 0.2 and 2.5µg/l were detected in all wet season samples whereas γ-HCH (0.2µg/l) was found in only one wet season sample. Recoveries of all pesticides ranged from 65 to 108%.

This study showed that the current levels of pesticides residues in the studied waters have no acute effects to aquatic biota. However, the levels of total DDT and dieldrin during the wet season might result in chronic effects to aquatic biota.

INTRODUCTION

Pesticides have become essential components of modern agricultural systems and in public health programmes. Their use has been considered to be vital in reducing crop losses and controlling vectors of human and livestock diseases. However, organochlorine pesticides such as DDT and aldrin, which have been extensively used in agriculture and public health programmes, are very persistent in nature. Their persistence and lipid
solubility make them major environmental pollutants. The accumulation of low concentrations of these pesticides in the body fat of mammals might pose potential hazards in the long run (Jensen, 1983).

These pesticides not only persist in target organisms and soil systems, but also enter into natural waters by percolation and runoff from agricultural land and channels, and from urban city sewage sites, thus affecting the quality of various water sources. The persistence of these organochlorines in water has a special significance as they are taken up by organisms like plankton and thus enter into the food chain.

Like many other tropical countries Tanzania has extensively used organochlorine pesticides in both agriculture and public health programmes. The exact amount of organochlorine pesticides that has been used is not known. The general use of some of these pesticides was banned while a significant amount was still in stock. Pesticide distributors were asked to stop importing the banned pesticides but were allowed to continue selling the existing stock. However, the customers also shied away from buying the stock and there were no disposal alternatives provided; this resulted in the accumulation of these obsolete pesticides. Tanzania is estimated to have 1000 tonnes of obsolete pesticides and veterinary drugs, mostly persistent organochlorines including DDT and dieldrin (Mmochi and Mberek, 1998). However due to the effectiveness of DDT as a broad spectrum insecticide, some of the pesticide dealers continue to illegally import, formulate and sell the pesticides under different trade names (NEMC, 1994).

Several studies on organochlorine pesticide contamination in water bodies have been conducted in other parts of the world, but very few investigations have assessed organochlorine pesticide residues in the water bodies of Tanzania and their impact to aquatic biota.

The objective of the current study was to investigate the patterns of occurrence and distribution of organochlorine pesticide residues in waters of Msimbazi and Kizinga rivers in Dar es Salaam and from the coastal marine environment between these rivers during the dry and wet seasons. Assessment of the potential risk such pesticide levels pose to aquatic organisms by comparison with available standard levels from other countries was also undertaken.

MATERIALS AND METHODS

Study area
The study was conducted at the Msimbazi and Kizinga rivers as well as at the Dar es Salaam marine coastal environment between December 1996 and January 1998. River Msimbazi is about 35km long, passes through the city industrial area and its catchment area is 300 square kilometres. Its basin is a significant agricultural zone supplying the city with most of its vegetable and fruit requirements (Stevenson et al., 1994). The river receives municipal and untreated waste from industries, forming the common outlet to the Indian Ocean for more than 30 industries (FAO/UNEP, 1982).
River Kizinga starts from Kazimzumbwi forest reserves and drains its water into the Indian Ocean at the Mtoni mangrove site. On its way to the Dar es Salaam coastal marine environment it passes through agricultural and residential areas and therefore receives both domestic and agricultural wastes. Waters from the rivers are normally used for watering vegetables, washing and occasionally for drinking.

The coastal area under study receives water from both rivers as well as large amounts of domestic and industrial effluent. The area is also characterised by harbour and ship fumigation activities.

The relevance of the study area is based on the premise that pesticides may be transported in streams, rivers and other municipal drainage systems water, either dissolved in the water or attached to suspended matter, and eventually reach the coast. At the coastal area persistent organochlorine pesticides like DDT and its metabolites will accumulate in sediments or concentrate in the food chain. Other less persistent pesticides may still affect fragile ecosystems by momentarily killing certain species of animals, plants or other organisms. Among the major reported chronic effects to the aquatic biota associated with organochlorine exposure (DDT in particular) in sediments is reproductive depression (Murdoch et al., 1997).

**Sampling**

Eight sampling stations were located within the study area based on industrial, agricultural and harbour activities. The samples were collected at four different times during both the wet and dry seasons. Early dry season and late dry season samplings were taken for the dry season, and wet season sampling was also composed of early rains and late rains samples. The two sampling trips per season were aimed at studying the variation of occurrence and levels of residues within the seasons.

Water samples were collected into a clean 1-litre glass bottle with a Teflon lid or glass stopper. The samples were then preserved with 3% dichloromethane to stop biological activities before being transported to the laboratory for extraction procedures.

**Analytical procedures**

Water samples were extracted by liquid - liquid extraction using dichloromethane and gel permeation chromatography (GPC) as well as sulphuric acid treatment clean-up techniques employed according to Guidelines for SADC Region, Monitoring Techniques series 3 (Åkerblom, 1995). The samples were then analysed with a Varian 3400 gas chromatograph fitted with a $^{63}$Ni electron capture detector and both SE-30 and OV 1701 mega bore columns (30m x 0.32mm x 0.5μm). The GC parameters and operational conditions were as follows:

- **Gases:** Carrier gas ($H_2$) at flow rate of 5ml/min and makeup gas ($N_2$) at flow rate of 25ml/min.
- **Temperature programme:** 90°C (1min) at 30°C/min to 180°C at 4°C/min to 260 °C (10min).
Identification and quantification were accomplished using external reference standards and relative retention times techniques. The results were confirmed using GC-MS in Sweden at the Department of Environmental Assessment of the Swedish University of Agricultural Sciences.

RESULTS AND DISCUSSION

Results
The average recoveries and method detection limits for identified residues are given in Table 1 (the values were not corrected for recoveries).

Among the wide range of analysed organochlorine pesticides in 32 water samples of both dry and wet seasons, only p,p'-DDT, p,p'-DDE, dieldrin and γ-HCH (lindane) were detected. During the dry season only p,p'-DDT and p,p'-DDE were identified whereas in wet season samples pesticides residues of dieldrin and γ-HCH were also detected at levels above the methods detection limits. The status of detected pesticide residues in both dry and wet seasons is given in Table 2. Full details of the residue measurements for dry and wet seasons are given in Appendix 1.

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Average % recovery and range, (n=4)</th>
<th>Average method detection limit (µg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p,p'-DDT</td>
<td>108 (98–114)</td>
<td>0.10</td>
</tr>
<tr>
<td>p,p'-DDE</td>
<td>92 (86–97)</td>
<td>0.05</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>106 (95–112)</td>
<td>0.04</td>
</tr>
<tr>
<td>γ-HCH</td>
<td>65 (61–72)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 2. Status of pesticide levels in 32 water samples in wet and dry seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Type of pesticide</th>
<th>Percentage of sample with pesticide</th>
<th>Mean concentration (µg/l)</th>
<th>Concentration range (µg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry season</td>
<td>p,p'-DDT</td>
<td>25%</td>
<td>0.20</td>
<td>N.D. – 0.4</td>
</tr>
<tr>
<td></td>
<td>p,p'-DDE</td>
<td>37.5%</td>
<td>0.12</td>
<td>N.D. – 0.2</td>
</tr>
<tr>
<td></td>
<td>Total DDT</td>
<td>37.5%</td>
<td>0.27</td>
<td>N.D. – 0.5</td>
</tr>
<tr>
<td>Wet season</td>
<td>p,p'-DDT</td>
<td>81%</td>
<td>0.20</td>
<td>N.D. – 0.3</td>
</tr>
<tr>
<td></td>
<td>p,p'-DDE</td>
<td>100%</td>
<td>0.23</td>
<td>0.05 – 0.45</td>
</tr>
<tr>
<td></td>
<td>Total DDT</td>
<td>100%</td>
<td>0.40</td>
<td>0.05 – 0.8</td>
</tr>
<tr>
<td></td>
<td>Dieldrin</td>
<td>100%</td>
<td>0.65</td>
<td>0.2 – 2.5</td>
</tr>
<tr>
<td></td>
<td>γ-HCH</td>
<td>6%</td>
<td>0.20</td>
<td>N.D. – 0.20</td>
</tr>
</tbody>
</table>

Figure 1a and 1b show the levels of organochlorine pesticide residues found in dry season water samples. Figure 1a represents the distribution during the early dry season and Figure 1b that for the late dry season. During the wet season, two sets of 8 samples each, collected during early and late rain, were analysed. The results for both early-rains
and late-rains seasons are presented in Figures 2a and 2b respectively. There was marked difference in the detection frequencies of pesticides. A high frequency of pesticide detection was observed in wet season samples but the frequency was significantly lower in dry season samples.

Residues of \( \text{p,p}'\)-DDT were detected in 25% of the dry season samples at a concentration range of N.D. to 0.4\( \mu \)g/l and in 81% of the wet season samples at concentration ranging from N.D. to 0.3\( \mu \)g/l. The mean concentration values of the detected \( \text{p,p}'\)-DDT for both dry and wet season was 0.2\( \mu \)g/l. This suggests no significant difference (\( p = 0.45 \)) on the levels of identified \( \text{p,p}'\)-DDT residues between the wet and the dry season, regardless of the notable difference in frequency of detection. The highest concentrations for both seasons were obtained at the Jangwani area. All the dry season
Figure 2a. Levels of pesticides residues detected in early wet season water samples

Figure 2b. Levels of pesticides residues detected in late rains season water samples
samples found to have p,p’-DDT residues were from Msimbazi River while in the wet season samples p,p’-DDT was found in almost all the studied water bodies.

All the wet season samples and 37.5% of the dry season samples had p,p’-DDE concentrations ranging from 0.05 to 0.45μg/l and N.D. to 0.2μg/l respectively. The highest concentration in the dry season samples was also found at Jangwani area whereas during the wet season the highest concentration was detected at both Jangwani and Tabata areas. The mean p,p’-DDE concentration was 0.23μg/l in the wet season and 0.12μg/l in the dry season. The areas with detectable p,p’-DDE residues depicted almost the same trend as that for p,p’-DDT residues.

Total p,p’-DDT (p,p’-DDT + p,p’-DDE) that was detected in 37.5% of the dry season samples and 100% of the wet season samples ranged from N.D. to 0.5μg/l and 0.05 to 0.8μg/l respectively. Their mean concentrations were 0.27μg/l in dry season and 0.4μg/l in wet season samples.

Dieldrin and γ-HCH were detected at concentration significantly above detection limits only during the wet season. The γ-HCH was found at concentration of 0.2μg/l in one sample collected at Kurasini mangrove estuarine areas during early rains. Dieldrin amounts ranging between 0.2 and 2.5μg/l were detected in all wet season samples. The maximum concentration was detected near Salender Bridge during early rains and at Kurasini during late rains. The seasonal mean value of dieldrin was 0.7μg/l. Statistical analysis of dieldrin concentration values between early rain season and late rain season showed no significant difference (p = 0.47).

**DISCUSSION**

**Variation in detection frequency and concentrations**

The frequency of detection of pesticides residues showed a marked seasonal variation. The frequency of all detected pesticides were observed to increase from the dry to the wet season. p,p’-DDT had an increase from 25% to 81%, p,p’-DDE detection frequency increased from 25 to 100%, dieldrin from 0 to 100% and that of γ-HCH from 0 to 6%. Mwanthi (1998) has reported similar observations. This increase of detection frequency might be caused by agricultural and domestic runoff flowing to the water bodies, which seem to be a potential source of pollution for surface water during the rainy season. The ability of pesticide residues to bind to soil/sediment particles depends on their lipophilicity which is estimated by their octanol-water partition K_{ow}. The higher K_{ow} of DDT and its metabolites (log K_{ow} = 6) as well as that of dieldrin (log K_{ow} = 4.8) may account for their significant increase in detection frequency from dry to wet season. The lower detection frequency of γ-HCH during the rainy season reflects its relatively lower K_{ow} (log K_{ow} = 3.7) and relatively quicker breakdown than the other residues.

Comparison of dry and wet season data reveals that the maximum concentrations of p,p’-DDE went from 0.2 to 0.5μg/l, total DDT from 0.5 to 0.8μg/l while dieldrin and γ-HCH change from non detectable levels to 2.5μg/l and 0.2μg/l respectively from the dry to the
wet season. This change in concentration could be accounted for by runoff which washes and releases pesticides bound to soil particles and other matrixes from treated areas directly to water bodies. The increase in concentration is also likely to be contributed by suspended particles, as the water samples were analysed without being filtered. Such increase in concentration has been also reported by MacKenzie-Smith et al. (1994) in their study of organochlorine residues in water from different rivers. In their study they found more than 70% of pesticide residues in unfiltered water was associated to suspended particles and in some samples 100% of dieldrin was associated with suspended particles. Our results are comparable and this may give appropriate explanation for the detection of dieldrin only during the rainy season.

However, the maximum concentration of $p,p'$-DDT was almost constant from the dry season to the wet season. The value of the detection constant for maximum concentration of $p,p'$-DDT at Jangwani sites in both seasons suggests the presence of point sources such as illegally used DDT along the river bank. This may also explain the presence of DDT in Msimbazi River sites only during the dry season.

In most cases the lowest concentration of detected residues were measured at the Harbour sampling site followed by the Ferry sampling sites. This could be due to the influence of dilution as both are deep-water sites and may be also due to lack of turbulent flow as this reduces the amount of suspended residues in water.

**Comparison with different standards levels**

There are no established maximum pesticide residue limits for surface water and even for drinking water for Tanzania. The only maximum residue level limits for surface fresh water and coastal and marine waters found in the literature were from the Philippines. According to water quality criteria for toxic and deleterious substances for coastal and marine water, the maximum limits for total DDT, dieldrin and γ-HCH are 50, 1 and 4μg/l respectively (DENR, 1990). The mean values of DDT, dieldrin and γ-HCH found by this study were therefore below the Philippines limits. However, individual sites such as Salender Bridge during early rains and Jangwani and Kurasini during late rains, showed higher level of pesticide residue than these limits.

Since fresh waters from the rivers are occasionally used for drinking by humans, the levels were then compared with WHO limits. The WHO limits are based on toxicological data and they therefore consider the pesticides individually as pesticides differ from one another in their toxicological properties. Drinking water limit values of the WHO are 1 and 0.03μg/l for DDT and dieldrin respectively (Dahi, 1989). The mean values of DDT for both dry and wet seasons are below these limit values but the obtained mean value of dieldrin is about 20 times above the limits. This also suggests that the fresh waters of Msimbazi and Kizinga rivers were not safe for drinking, particularly during the wet season.

The residue levels found in this study were generally lower than those found in previous studies on Tanzania aquatic bodies (Mmochi and Mberek, 1998), and much lower than those determined in surface waters in India (Nayak et al., 1995).
Effects of residue levels to aquatic biota

Comparison of the results from our study to the water quality criteria and guidelines for the protection of aquatic life shows that the average over both seasons, of pesticide residue concentrations in the waters analysed in this study, were below the USA acute criteria for protection of aquatic life (Table 3). The levels are also below the Quebec acute criterion of DDT and its metabolites (1.1 μg/l) for protection of aquatic life (MacDonald, 1994). However, the wet season concentration of dieldrin at Kurasini was comparable to the USA dieldrin acute criterion for protection of aquatic life. In contrast, all the wet season average concentrations of total DDT, dieldrin, and dry season average concentration of total DDT in Msimbazi exceeded the USA chronic criteria as well as the recommended concentration of unfiltered sample of Ontario jurisdictions for protection of aquatic life.

The wet season γ-HCH level in Kizinga River was lower than the USA chronic criterion but higher than the Ontario recommended levels for unfiltered samples. The average levels of DDT, dieldrin and γ-HCH from this study are again above the Canada guidelines (DDT; 0.004 μg/l, dieldrin and γ-HCH; 0.01 μg/l) (MacDonald, 1994) for protection of aquatic life. Therefore, although the levels of pesticides found in our study would indicate no acute effects to aquatic organisms, the levels of total DDT and dieldrin during the wet season would point to the possibility of long term adverse effects on aquatic biota.

### Table 3. Comparison of residues levels with the water quality criteria and guidelines for the protection of aquatic life (MacDonald, 1994)

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Total - DDT</th>
<th>Dieldrin</th>
<th>γ-HCH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dry</td>
<td>wet</td>
<td>dry</td>
</tr>
<tr>
<td>Present study:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Msimbazi River</td>
<td>0.3</td>
<td>0.5</td>
<td>N.D.</td>
</tr>
<tr>
<td>Marine waters</td>
<td>N.D.</td>
<td>0.1</td>
<td>N.D.</td>
</tr>
<tr>
<td>Kizinga River</td>
<td>N.D.</td>
<td>0.4</td>
<td>N.D.</td>
</tr>
<tr>
<td>USA:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>acute</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chronic</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ontario unfiltered sample</td>
<td>0.003</td>
<td>0.001</td>
<td>0.01</td>
</tr>
</tbody>
</table>

N.D. - not detected.

CONCLUSION

This study has shown that there was a marked difference in frequency of organochlorine pesticide residues found in the study area between the wet and dry seasons. The difference was mainly due to the contribution by runoff water which washes and releases pesticides bound to soil particles into water bodies. The variation of pesticides found was attributed to the presence of suspended particles as the samples were extracted without being filtered. The residue concentrations were much below the Philippines maximum limits for
coastal and marine water. However they were above the WHO maximum acceptable concentrations for drinking water and therefore, these waters are not safe for direct human consumption.

The study also revealed that the detected residue levels were not likely to give direct acute effects to aquatic organisms but they were likely to cause chronic effects to aquatic organisms.

ACKNOWLEDGEMENT

The authors are very grateful to Associate Professor M. Åkerblom of International Science Programme, Uppsala University, Sweden, for her guidance and contribution in the whole period of this study. We are indebted to Gunborg Alex of Department of Environmental Assessment of the Swedish University of Agricultural Sciences, Sweden for carrying out GC-MS analysis to verify the results. We also thank the pesticide group of the Institute of Marine Sciences and the Chemistry Department of the University of Dar es Salaam for various discussions and encouragement during the study. This study was funded by the Pesticide Project within Sida/SAREC Regional Marine Science Program.

REFERENCES

Appendix 1. Organochlorine pesticides residues (µg/l) measured at the different sites

a) Dry seasons

<table>
<thead>
<tr>
<th>Site</th>
<th>DDT</th>
<th>DDE</th>
<th>Site</th>
<th>DDT</th>
<th>DDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW1</td>
<td>0.13</td>
<td>0.08</td>
<td>TW2</td>
<td>N.D.</td>
<td>0.16</td>
</tr>
<tr>
<td>JW1</td>
<td>0.39</td>
<td>0.09</td>
<td>JW2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>SW1</td>
<td>0.28</td>
<td>0.08</td>
<td>SW2</td>
<td>N.D.</td>
<td>0.12</td>
</tr>
<tr>
<td>FW1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>FW2</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>HW1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>HW2</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>KrW1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>KrW2</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>MW1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>MW2</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>KW1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>KW2</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
</tbody>
</table>

b) Wet seasons

<table>
<thead>
<tr>
<th>Site</th>
<th>DDT</th>
<th>DDE</th>
<th>dieldrin</th>
<th>γ-HCH</th>
<th>Site</th>
<th>DDT</th>
<th>DDE</th>
<th>dieldrin</th>
<th>γ-HCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW3</td>
<td>0.19</td>
<td>0.43</td>
<td>0.67</td>
<td>N.D.</td>
<td>TW4</td>
<td>0.1</td>
<td>0.45</td>
<td>0.49</td>
<td>N.D.</td>
</tr>
<tr>
<td>JW3</td>
<td>0.25</td>
<td>0.20</td>
<td>0.54</td>
<td>N.D.</td>
<td>JW4</td>
<td>0.33</td>
<td>0.45</td>
<td>1.02</td>
<td>N.D.</td>
</tr>
<tr>
<td>SW3</td>
<td>0.21</td>
<td>0.22</td>
<td>1.24</td>
<td>N.D.</td>
<td>SW4</td>
<td>0.11</td>
<td>0.18</td>
<td>0.59</td>
<td>N.D.</td>
</tr>
<tr>
<td>FW3</td>
<td>N.D.</td>
<td>0.18</td>
<td>0.34</td>
<td>N.D.</td>
<td>FW4</td>
<td>0.1</td>
<td>0.08</td>
<td>0.24</td>
<td>N.D.</td>
</tr>
<tr>
<td>HW3</td>
<td>N.D.</td>
<td>0.08</td>
<td>0.21</td>
<td>N.D.</td>
<td>HW4</td>
<td>N.D.</td>
<td>0.05</td>
<td>0.22</td>
<td>N.D.</td>
</tr>
<tr>
<td>KrW3</td>
<td>0.18</td>
<td>0.19</td>
<td>0.46</td>
<td>0.2</td>
<td>KrW4</td>
<td>0.22</td>
<td>0.17</td>
<td>2.49</td>
<td>N.D.</td>
</tr>
<tr>
<td>MW3</td>
<td>0.22</td>
<td>0.15</td>
<td>0.42</td>
<td>N.D.</td>
<td>MW4</td>
<td>0.22</td>
<td>0.18</td>
<td>0.52</td>
<td>N.D.</td>
</tr>
<tr>
<td>KW3</td>
<td>0.20</td>
<td>0.4</td>
<td>0.4</td>
<td>N.D.</td>
<td>KW4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.45</td>
<td>N.D.</td>
</tr>
</tbody>
</table>

The role of mangroves in the nutrient cycling and productivity of adjacent seagrass communities, Chwaka Bay, Zanzibar

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ABSTRACT

The impact of mangrove-derived particulate organic matter (POM) on nutrient dynamics and the productivity of an adjacent seagrass community were investigated in the Chwaka Bay (Zanzibar). Analysis of the C:N ratio of POM in the water ebbing from the forest produced values ranging from 2 to 11 which is the same range of values as that of the mangrove plant materials. An examination of the carbon and nitrogen contents of the sediment reveals a gradient of concentrations from the site closest to the forest outwards, with the site adjacent to the mangroves enriched with both total organic nitrogen (TOC) and total nitrogen (TN). These results indicate that there is export of POM from the mangroves to the seagrass beds but deposition of this material is restricted to the seagrass communities closest to the mangroves. However, measurements of primary production showed that the site farthest from the mangrove forest had a gross community production of 1029 gCm\textsuperscript{-2}y\textsuperscript{-1} compared to 467 gCm\textsuperscript{-2}y\textsuperscript{-1} at the site closest to the mangroves, the latter site being a direct recipient of the mangrove derived POM. Apparently the high primary production at the site farthest away from the forest is not directly coupled to mangrove export but rather to the contribution of the high epiphytic communities found at this site. These data show that the Chwaka mangrove forest exports POM to the adjacent seagrass communities; however, the direct coupling between mangrove outwelling and seagrass production is restricted to the sites closest to the forest and that the influence of the mangrove POM fades with distance from the forest.

INTRODUCTION

An intriguing feature of many tropical coastal areas is the occurrence, in very close proximity to one another, of mangroves, seagrasses and coral reefs. Understandably this has led to recurrent speculations of the existence of biological and chemical links between these ecosystems. Obviously, the extent and nature of this material exchange will depend on a
number of factors, foremost of which are the geomorphology and hydrodynamic characteristics of the particular area (e.g. Wolanski et al., 1992; Woodroffe, 1985). Since they typically lie between mangrove forests and more offshore areas, seagrass meadows represent a potential point of convergence for the different influences that may be exerted by adjacent biotopes and ecosystems. Further, despite their occurrence in waters which are generally poor in dissolved nutrients, primary production in seagrass communities is typically very high with a reported range in the order of 220–1750 gCm²/y (den Hartog, 1977; Moriarty et al., 1990; Johnson and Johnstone, 1995). Such high production levels suggest high nutrient requirements and a number of studies have suggested seagrass production to be nutrient-limited (Short et al. 1990; Perez et al., 1991; Fourqueine et al., 1992a,b). Short (1987) suggested that seagrasses occurring in tropical environments on carbonate sediments often experience phosphorus limitation. Consequently, seagrass communities appear to typically require an external source of these nutrients in order to sustain their high production. This reasoning has strengthened speculation that seagrass communities may depend on subsidies obtained from adjacent ecosystems such as mangroves for their maintenance. The ability of seagrasses to efficiently trap suspended material makes them well suited to this phenomenon (Short and Short, 1984; Scoffin, 1970; 1991; Hemminga et al., 1991; 1994), and provides an avenue through which they can meet their nutrient demands.

In broad terms, the acquisition of nutrients and the maintenance of a balanced nutrient budget in seagrass communities rely on a variety of processes and nutrient sources. These include the direct uptake of nutrients by leaves from the water column, nitrogen fixation, internal recycling, and the trapping of organic matter and minerals (Hemminga et al., 1991). Considering the oligotrophic conditions prevailing in most tropical waters, nutrient assimilation through the leaf is probably a rather limited source (Penhale and Thayer, 1980; Short, 1987; Hemminga et al., 1991). However, nitrogen fixation has long been recognised as an important source of new nitrogen in seagrass communities (Patriquin and Knowles, 1972; Capone and Taylor, 1977, 1980; Smith and Hayasaka, 1982). Shieh et al., (1989), for example, observed large numbers of nitrogen-fixing bacteria in the rhizosphere of Zostera marina. Estimates of daily inputs of nitrogen to seagrass meadows through nitrogen fixers range from 0–24 mg/m²/d (McRoy et al., 1973; Capone and Taylor, 1980). Seagrasses themselves may also maintain efficient levels of internal nutrient cycling. This is achieved by the remobilisation and translocation of nutrients from older senescing parts prior to their loss from the plant (Nienhuis et al., 1989; Hemminga et al., 1991; Erftemeijer and Middelburg, 1995). Pedersen and Borum (1992, 1993) have shown that internal cycling (resorption) in Z. marina from mesotrophic and eutrophic temperate environments can account for 12–27% of a plant nitrogen requirement. At a community level, internal recycling of nutrients within seagrass communities can also be accomplished through rapid mineralisation of organic matter in seagrass beds which are then taken up by the plants (Erftemeijer and Middelburg, 1995).
In addition to the above sources of nutrients, trapping and sedimentation in seagrass beds are also important mechanisms by which seagrasses can acquire nutrients. This phenomenon in seagrass beds is facilitated by the reduction of current velocity brought about by seagrass canopy, thus reducing the sediment-bearing capacity of the water (Hemminga et al., 1991). In theory, sedimentation could provide seagrasses with a major fraction of the nutrients they require for biomass production. For example, Kenworthy and Thayer (1984) estimated that the organic nitrogen input from phytoplankton to an eelgrass community amounted to about 7 to 45g N/m²/y. This is a considerable contribution if one considers the range of production values seagrass beds can exhibit. This amount is more than what Hemminga et al. (1991) estimated to be demanded for biomass production of 5 to 35g N/m²/y in seagrass communities in Gazi Bay, Kenya. Obviously, the figures given by Kenworthy and Thayer (1984) cannot be representative of all seagrass communities since sedimentation may differ strongly between sites (Hemminga et al., 1991), but it shows the importance of this phenomenon in the replenishment of nutrients to seagrass communities.

Several studies have shown the export of materials from mangroves to the other ecosystems in the form of particulate matter (POM) (e.g. Boto and Bunt, 1981; Robertson, 1986; Flores-Verdugo et al., 1987). In their study in Gazi Bay, Kenya, Hemminga et al., (1994) demonstrated a strong coupling between a mangrove forest and nearby seagrass communities via the exchange of POM. Moreover, the seagrass zone appeared to act as a buffer between the mangrove forest and the adjacent coral reef by efficiently trapping the organic matter derived from the mangroves.

In the light of this, many tropical seagrass communities can be conceptualised as a transformation and production platform within a larger coastal ecosystem, with the larger ecosystem being composed of, for example, mangroves, seagrasses, open lagoon or sediment areas, and often coral reefs. The seagrass communities examined in this study are proposed to fill this niche.

Chwaka Bay, which lies on the north east coast of Unguja Island, Zanzibar, is comprised of significant areas of seagrass and is fringed on its southern shoreline by extensive mangrove forests. Prior to this study, no information existed on the productivity of these seagrass communities, although there have been some studies on the hydrography of the Bay (Wolanski, 1989). Information also exists on the nutrient dynamics and community structure of the mangrove forests (Shunula, 1989; Mohammed and Johnstone, 1995; Mohammed and Johnstone, in prep.). Further, studies on the potential export of nutrients from the mangrove areas in Chwaka Bay indicate that there is little or no export of dissolved inorganic nutrients (Mohammed and Johnstone, 1995; Mohammed and Johnstone, in prep.). Based on this observation and the consistently high turbidity of outgoing waters, Mohammed and Johnstone (1995) proposed that the export of particulate organic matter (POM) may be the avenue of release for nutrients being lost from the mangrove forests. In turn, this POM may be
important for the seagrass communities that receive the outgoing waters on the ebb tide.

The central aim of the present study was to examine the community metabolism of the seagrass communities adjacent to the mangroves of Mapopwe Creek, in Chwaka Bay, with the purpose of assessing the contribution that mangrove-derived POM might make to their nutrient dynamics. By establishing the level of dependence that the seagrass communities might have on POM, it might be possible to ascribe the role of the adjacent mangrove communities in their maintenance and productivity.

MATERIALS AND METHODS

Study area
The study was conducted in the Chwaka Bay on the east coast of Unguja Island, Zanzibar, about 34km from Zanzibar Town (Figure 1a), during the months of July and August 1997. The Bay is a shallow intertidal water body with an average depth of 3.2m and covers an approximate area of 50km² at high spring tide, and 20km² at low spring tide (Cederlöf et al., 1995). It is characterised by large intertidal flats partly covered with mixed assemblages of algae and seagrass communities. On the landward side in the south, the Bay is fringed by a dense mangrove forest which is drained by a number of tidal creeks, the largest of which is the Mapopwe Creek which is by far the main water exchange route between the forest and the Bay. A modest fragmented coral reef occurs at the entrance of the Bay which is part of the extensive reef that fringes the east coast of Unguja Island. An important feature of the bathymetry of the Bay, which is particularly relevant to this study, is the existence of a limestone sill at the entrance of the Mapopwe Creek. Wolanski (1989) has shown that the limestone sill hinders water exchange between Mapopwe Creek and the open bay, and can essentially isolate creek and bay waters at low tide.

Metabolism studies and sampling were conducted at three sites along an approximate transect from the bay side of the sill into the main bay (Figure 1b). Site 1 was situated on the inner side of the bay, about 500m from the mouth of the Mapopwe Creek. This site is characterised by a mixed community of seagrasses (mainly Cymodocea serrulata and Cymodocea rotundata) patchily interspersed with coralline algae (Halimeda taenica and Halimeda tuna) and brown algae (Cystoceris trinodis, Cystosperis myrica, and Dictyota). Site 2 was located where water from the two westernmost mangrove areas connect, about 2km from site 1. This site supports a mixed culture of Thallasodendron ciliatum and Enhalus acoroides and some brown algae, mostly Cystoceris and Dictyota. Strong tidal currents characterise both sites 1 and 2. Site 3 is located farthest from the forest, about 2km from site 2. It is mostly covered by a monoculture of Enhalus acoroides, with some Thallasodendron ciliatum. Conditions at this site were more or less oceanic with relatively deep (>4m) and clear water.
Sampling and analysis of sediments

Physico-chemical characteristics of sediment

In order to characterise the sediments at each site, sediment samples were collected from each location and analysed to determine total organic carbon content (TOC), total nitrogen content (TN), water content, and sediment porosity. To do this, between 4 and 6 sediment cores were randomly collected by hand at each site using a combination of cut-off 50ml plastic syringes and 44mm-diameter Plexiglass tubes. In both cases an adjustable stopper was used to minimise sediment compression and to maintain sediment structure where relevant.

For TOC and TN determinations, the upper 2cm of sediment was sampled using a cut-off 50ml plastic syringe. The collected samples were immediately placed in aluminium foil and stored on ice in the field for later analysis in the laboratory. For the estimation of water content and porosity, the upper 10cm of sediment was collected using Plexiglass
tubes and a known weight of this sediment was oven-dried at 65°C to constant weight. The water content was then calculated from the difference in weight, and sediment porosity was taken as the ratio of the water volume to the total weight of the sediment sample (Corredor and Morell, 1989). The dried samples from the above analysis were subsequently dry-sieved and the weight of material passing through each size range was recorded. The percentage by weight of each fraction to the total weight of the sediment sample was calculated. Results are given in $\phi$ (grain size index), where $2^\phi$ is the particle diameter in mm.

Total organic carbon (TOC) and total nitrogen (TN) content of sediments was determined using a LECO-900 CHN analyser. For practical reasons sediment cores were collected at low tide when sediments were covered by $\leq 1$m of water. After collection, all samples were stored in an insulated icebox and transported to the laboratory for analysis.

**Estimation of sediment nutrient concentration profiles**

Sediment samples for the estimation of depth profiles of $\text{NH}_4^+$ and $\text{NO}_3^- + \text{NO}_2^-$ (DIN) were collected using a 'Kajak' type sediment sampler with Plexiglas core sleeves that had an internal diameter of 8cm. Only the upper 15cm of each core was used for profile determinations and a total of between 4 and 6 cores were taken randomly at each site. Immediately upon sampling, the cores were sectioned at half centimetre intervals to a depth of 2cm and then at one cm intervals to 5cm. Below this depth 1cm sections were collected between 9 and 10cm and 14 and 15cm. The samples were held in airtight containers and transported on ice back to the laboratory for analysis. Once in the laboratory, the respective sediment sections were centrifuged at 3000G for 10 minutes to remove porewater. The porewater samples so collected were then filtered through pre-washed 0.45µm Whatman GF/F filters and stored when necessary at -20°C until analysed for nutrients. All samples were subsequently analysed for $\text{NO}_3^-$, $\text{NO}_2^-$ and $\text{NH}_4^+$. The analysis of $\text{NO}_3^-$ and $\text{NO}_2^-$ was conducted using a modified version of the Autoanlyser methods as described by Technicon for the Technicon AAII Autoanlyser. Ammonium analysis was achieved using the method described by Parson et al. (1984). Unfortunately we were unable to obtain enough porewater for the analysis of ammonia at all depths so the depth profile for this nutrient is limited to mean values over the upper 10cm of sediment. In addition, total extractable ammonium concentrations were determined for the upper 2cm of sediment by extraction with 1N KCl (1:1v/v). This ratio was earlier determined as being adequate to extract all bonded $\text{NH}_4^+$ in the sediment samples under study. The KCl-sediment slurry was centrifuged as for porewater samples and the resulting solution was handled and analysed in the same manner as porewater samples described above.

**Measurement of nitrification and denitrification rates**

Nitrification was measured on intact sediment cores by the inhibition technique using allylthiourea (ATU) (Hall, 1984). For this, between 8 and 10 x 4cm-diameter sediment
cores were collected randomly at each site to a depth of 10cm using Plexiglas cores. The respective corers had self-sealing injection holes at 0.5cm intervals along both sides to facilitate the injection of the ATU inhibitor. The incubations were started by injecting 60µl of ATU solution at 0.5cm intervals to give a final concentration of 10mg/l ATU in the porewater and in the overlying water. The ATU was injected in five different directions in each hole to maximise distribution of the inhibitor. The cores were then covered with rubber stoppers carrying small magnetic stirrers that were suspended about 1cm above the sediment surface. A rotating magnet placed outside the cores facilitated the stirring of the water column.

The inhibited cores were then incubated in time series so that at time zero (on injection) half of the cores were immediately sectioned and the porewater removed for nutrient analysis. The remaining cores were then incubated at in situ temperatures for between 8 and 10 hours, and then also sectioned. At the end of the incubation period, sediment and water samples were collected as above and KCl extraction of NH$_4^+$ was also conducted on the sediment to determine adsorbed NH$_4^+$ levels. The porewater removal and analyses were conducted as for porewater samples described above. The rate of accumulation of ammonia in the samples was taken as a measure of the nitrification rate (Hall, 1984). Further, incubations were carried out under both natural light and dark conditions in order to assess any possible effect of micro-phytobenthos on nitrification rates.

Measurements of denitrification rates were carried out using the nitrogen isotope pairing method of Nielsen (1992). Six randomly chosen sediment cores were collected from the three sites as described above using Plexiglass cores to a sediment depth of 15cm. On commencing the incubations, a known volume of 100mM stock solution $^{15}$NO$_3^-$ was added to the overlying water phase in each core to give a final NO$_3^-$ concentration of approximately 50µM. The water above the cores was kept in motion using magnetic stirrers as previously described. The cores were then sealed and left to incubate for about 4.5hours. After the incubation period, 50µl ZnCl$_2$ (1g/ml) were added into the sediment to stop further microbial activity. The water column and the sediment were then mixed thoroughly with a spatula to introduce air and thus stop the denitrification process. Samples of the resultant slurry were then collected by means of a syringe and transferred into pre-evacuated 5ml Extainers (Labco Ltd, Bucks, UK). The containers were fitted with a screw cap equipped with gas tight injection septum. Fifty microlitres (50µl) of ZnCl$_2$ were added into the Extainers to hinder further microbial activity. The samples were subsequently analysed with a mass spectrometer to determine the relative ratios of $^{28}$N$_2$, $^{28}$N$_2$ and $^{30}$N$_2$ according to the method of Nielsen (1992). Water samples from each incubation were also taken and analysed for NO$_3^-$ using the methods described above for porewater nutrient analysis.

**Measurement of water-borne particulate organic matter (POM)**

In order to estimate the movement of POM between the open bay and the inner mangrove creek, water samples were collected over a full tidal cycle for POM determinations.
Duplicate 1 litre water samples were collected every hour over a full tidal cycle from a station (M) at the mouth of the Mapopwe Creek (Figure 1). Samples were collected equidistant from the water surface and benthos to minimise any effect from surface-borne particles and re-suspension from the creek bed. On collection, the samples were filtered through a pre-washed Whatman GF/F filter and stored on ice for transport to the laboratory. Once in the laboratory, the filters were oven-dried to constant weight at 55°C and then divided so that one half was directly analysed for total carbon (TC) and total nitrogen (TN), and the remaining half was treated with a 25% HCl solution to remove carbonates. This was then also analysed for TC and TN. All TC and TN analyses were conducted using a LECO-CHN 900 elemental analyser. The amount of carbonate and organic carbon was then determined by difference from the values obtained.

Estimation of community production and community biomass
Measurement of community production was carried out at sites 1, 2 and 3. Measurements were carried out using 4 Plexiglas domes (for details of domes, see Johnstone et al., 1989; Johnson and Johnstone, 1995). Each dome enclosed an area of about 0.28m² and contained a water volume of 216 litres. Each dome was anchored over the respective seagrass areas by means of a steel base, which was driven into the sediment several days prior to the experiments. Additional anchorage was obtained from cement blocks located adjacent to the domes and connected with nylon lines. The water inside the domes was kept in motion with the help of Attwood Mini-King 360 pumps, pumping at a rate of 600l/h. The pump was connected to a tube which drew water from the lower part of the dome and discharged it into the upper spherical section. Prior tests with food dyes had shown this the best way of simulating the mixing that was observed in the seagrasses without the presence of the domes.

The domes were deployed at low spring tide at a depth of approximately 1.5m; but towards the end of the experiment, they were covered by at least 5m of water. Community primary production was estimated from the rate of oxygen evolution over the 12 hour daily light period and respiration was estimated from oxygen uptake using the same configuration but with lightproof black plastic cover over the respective domes. Oxygen concentrations were measured in situ with a WTW OXI-Meter 191 combination oxygen and temperature meter. The electrode was pushed into the entrapped water through a sealable port on the upper spherical part of the dome. The oxygen values were converted to carbon fixed by using a factor of 0.31 (Schramm et al., 1984) and using a respiratory quotient (RQ) and a photosynthetic quotient (PQ) of 1. At the end of the experiments, all above-surface biomass, including seagrasses, algae and epiphytes were collected from the sites under the domes. The seagrasses and algae were identified to at least genus level, and the relative epiphyte cover was calculated from area estimations under microscopic examination of seagrass blades. All the collected material was then dried to constant weight at 70°C and the biomass calculated from the total weight obtained. Total organic carbon (TOC) and TN of the seagrass and epiphyte
material were then determined by analysing randomly chosen replicate samples of the respective material on a LECO CHN-900.

**Sediment-water nutrient exchange**

In addition to community production, measurements were also made of the exchange of dissolved nitrogen species and soluble reactive phosphorus (SRP) across the sediment water-interface at the three sites. To do this, samples were collected using an acid-washed 50ml plastic syringe with the needle pushed through a self-sealing sampling port placed on the upper side of each dome. Samples were taken at 1 hourly intervals for six hours during both light and dark incubations. The samples were immediately filtered through a pre-rinsed Whatman GF/F filter and placed on ice for transport to the laboratory. The samples were subsequently analysed for $\text{NH}_4^+$ and $\text{NO}_3^- + \text{NO}_2^-$ (DIN) and SRP. Ammonium and SRP concentrations were determined using the methods of Parson et al. (1984). Nitrate and nitrite concentrations were determined on an auto-analyser as described in the previous sections. The rate of exchange of the nutrients between the water column and enclosed community was computed from the rate of change in nutrient concentrations over time.

**RESULTS**

**Sediment characteristics**

Results of the grain size analysis showed that sediment at sites 1 and 2 had a more-or-less similar distribution pattern but differed significantly from the distribution pattern found at site 3 (Figure 2). Generally, the sediments at site 1 and 2 were coarse and consisted to a large extent of fragments of the calcareous alga *Halimeda*. Moreover, shell fragments were also commonly found at site 1 and, as is discussed later, there was also a significant component made up of carbonate fragments from calcareous

![Figure 2. Distribution of sediment grain size with depth (i) Channel Bank, (ii) Forest, (iii) Channel sites in the Mapopwe Creek (n=6)](image-url)
alga such as *Halimeda*. In addition, both sites 1 and 2 are exposed to much stronger water currents which would sort out the finer sediment material. In comparison to these sites, site 3 showed a clear shift toward a generally finer grained sediment. Also, variation between replicate cores was much lower at this site reflecting a more stable and regular sediment environment.

Notably, TOC and TN levels showed an inverse relationship with sediment grain size, with the highest levels of both TOC and TN occurring in the coarse sediments at sites 1 and 2 (Table 1). Overall, TOC and TN levels decreased along the transect from site 1 to site 3 although C:N ratios did not show the same pattern. In contrast to TOC and TN values, the lowest mean C:N ratio was observed at site 1 and values increased toward the outer sites (Table 1). It should be noted, however, that the difference in means is tentative since the variance between replicates precluded its statistical confirmation. As also shown in Table 1, both sediment water content and porosity showed a clear decrease as from site 1 to site 3. This is considered to reflect the differences observed in sediment grain size composition and probably the intensity of tidal currents at the respective sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Water content %</th>
<th>Porosity %</th>
<th>TOC % dw⁻¹</th>
<th>TN % dw⁻¹</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>58.85 ± 4.68</td>
<td>71.0 ± 1.1</td>
<td>1.62 ± 0.48</td>
<td>0.34 ± 0.04</td>
<td>6.6 ± 1.3</td>
</tr>
<tr>
<td>Site 2</td>
<td>51.48 ± 3.49</td>
<td>63.5 ± 0.7</td>
<td>1.16 ± 0.37</td>
<td>0.14 ± 0.03</td>
<td>8.1 ± 3.2</td>
</tr>
<tr>
<td>Site 3</td>
<td>36.19 ± 1.60</td>
<td>53.1 ± 3.3</td>
<td>0.37 ± 0.17</td>
<td>0.04 ± 0.01</td>
<td>8.6 ± 2.8</td>
</tr>
</tbody>
</table>

Sediment nutrient concentration profiles

The limited amount of porewater available from sediment samples restricted ammonium determinations to the upper 4cm of sediment but the results of these samples showed site 3 to have a lower mean NH₄⁺ concentration in porewater than the other two sites; although these differences were not statistically significant. The values recorded were 20.2 ± 8.1 μM.N, 22.4 ± 6.1 μM.N and 12.0 ± 7.6 μM.N for sites 1, 2 and 3 respectively. The KCl extractable NH₄⁺ pool showed a similar pattern with values of 25.6 ± 11.7 μM.N, 28.8 ± 8.4 μM.N, and 16.0 ± 11.1 μM.N for sites 1, 2, and 3 respectively. Further, the mean concentration of NH₄⁺ in sediment porewater was consistent with depth of sediment down to the 4cm limit examined.

With regard to NO₃⁻ and NO₂⁻ concentrations, initial analysis indicated that NO₂⁻ concentrations were commonly at or below the limits of detection. Given this, and the limited amount of porewater available, it was decided to combine analyses so that the data presented here is NO₃⁻ and NO₂⁻ combined; defined here as NOₓ⁻.

Depth profiles showed that all sediments had a maximum NOₓ concentration at between 2 and 4cm sediment depth (Figure 3) although the peak concentration at site 2 was much lower than observed at sites 1 and 3. On two separate occasions NOₓ was
detected at sediment depths of 9.5 and 14.5cm although concentrations were around the limits of detection on one of the two occasions. It was further observed on closer inspection of the sediments at these sites that there was a considerable number of burrowing animals and it was easy to find various forms of animal burrows. Concentrations of NH₄⁺ are
within the range of 5–40μM previously reported in the literature from tropical seagrass beds but those of NO\textsubscript{x} were significantly higher (Boon, 1986; Montgomery et al., 1979; Patriquin, 1972). The elevated NO\textsubscript{x} level is thought to be due to intense animal activity and the irrigation of sediments due to the strong currents prevalent at the study sites. There was no significant difference in the concentration of these nutrients between sites (Kruskal-Wallis, p>0.05).

**Sediment nitrification and denitrification rates**

Nitrification rates varied between replicate incubations and between sites although there was no statistical difference in the means from each site (Table 2). As summarised in Table 2, nitrification rates ranged from -1.3 to 12μmol.N/m\textsuperscript{2}/h. Also, there was no difference in mean rates measured in light and dark conditions at each site. Unfortunately there are few similar measurements from tropical seagrass communities to compare our data with although those available show a range of between 0.4 to 3 nmol.N/g/h calculated per gram dry weight sediment (Horrigan and Capone, 1985; Koike and Hattori, 1978). For the sake of comparison we assume a mean water content of 50% and a sediment density of 1.5 g/cm\textsuperscript{3} for their sediments, we re-calculate these values to be in the order of 6 to 45 μmol.N/m\textsuperscript{2}/h. This range therefore includes the values observed in the present study.

<table>
<thead>
<tr>
<th>Site</th>
<th>Nitrification (μN/m\textsuperscript{2}/h)</th>
<th>Denitrification (μN/m\textsuperscript{2}/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- 1.3 ± 14.7</td>
<td>1.25 ± 1.18</td>
</tr>
<tr>
<td>2</td>
<td>12.0 ± 13.4</td>
<td>0.85 ± 0.84</td>
</tr>
<tr>
<td>3</td>
<td>6.1 ± 11.5</td>
<td>0.37 ± 0.64</td>
</tr>
<tr>
<td>3</td>
<td>10.2 ± 8.8</td>
<td>1.89 ± 2.69</td>
</tr>
<tr>
<td>2</td>
<td>3.1 ± 14.9</td>
<td>2.72 ± 1.10</td>
</tr>
<tr>
<td>3</td>
<td>4.9 ± 11.2</td>
<td>0.67 ± 0.70</td>
</tr>
</tbody>
</table>

Denitrification rates ranged from 0.37 to 2.72μmol.N/m\textsuperscript{2}/h (Table 2) and the isotope ratios showed this to be entirely due to denitrification supported by water column NO\textsubscript{x}; i.e. non-coupled denitrification. Coupled denitrification was not observed in sediments from any of the study sites. There was no significant difference in denitrification rates between the sites (Kruskal-Wallis, p = 0.24) or between dark and light incubations (Mann-Whitney U-Wilcoxon rank sum W test, p = 0.17).

**Nutrient fluxes and water column nutrient levels**

Generally the concentration of nutrients in the experimental domes remained rather constant during the course of the flux experiments. However, a small but highly variable uptake of NH\textsubscript{4}{+} and NO\textsubscript{x} was observed at all sites. The mean NH\textsubscript{4}{+} flux for each site was 54.0μmol N/
m²/h (site 1), 45.9μmol N/m²/h (site 2), and 31.6μmol N/m²/h (site 3) whilst mean NOₓ fluxes were 29.8 μmol N/m²/h, 117.2 μmol N/m²/h and 82.2μmol N/m²/h for the same sites respectively. No flux was observed for SRP at any site.

Mean water column concentrations of dissolved inorganic nitrogen (DIN; NH₄⁺ + NO₃⁻) were 22.6 ± 1.3, 23.2 ± 4.8 and 17.5 ± 1.6μmol N/l at site 1, 2 and 3 respectively. These values did not differ significantly with those of the water column outside the domes. By comparison, the concentration of SRP in the domes showed a maximum over site 1 although concentrations at all sites remained constant over the course of the experiment. Mean SRP concentrations were 2.60±0.3, 1.10 ± 0.1 and 1.2 ± 0.2 μmol P/l at site 1, 2 and 3 respectively. Water column concentrations of SRP outside the domes were 1.95 ± 0.01, 1.2 ± 0 and 1.2 ± 0 μmol P/l at site 1, 2 and 3 respectively.

Community production, biomass and species composition

Figure 4 shows mean gross primary production at the three sites. These production values are within the range reported in the literature for seagrass communities (den Hartog, 1977; Johnson and Johnstone, 1995; Moriarty et al., 1990; Pollard and Moriarty, 1990). Site 3 showed the highest gross production compared to the other sites while site 2 had the lowest. Comparison of net primary production and respiration at the three sites shows that at sites 1 and 2, p< R while at site 3, p > R. This suggests that the seagrass communities at sites 1 and 2 are essentially heterotrophic while those at site 3 are autotrophic.

![Figure 4. Gross primary production (community production) in the Chwaka Bay (mean ± SD, n=6)](image)

In terms of biomass, there were also significance differences between sites (ANOVA, p< 0.01). Seagrass and epiphyte biomass were inversely related to community production rates with site 2 showing the highest biomass and site 3 the lowest. Mean biomass estimates were 362 ± 32, 470 ± 49 and 100 ± 28g dry weight per m² at sites 1, 2, and 3 respectively (Figure 5). There were also variations in the percentage of epiphytic cover among the sites with a trend toward increasing epiphytic cover from the site closer to the mangroves to the outermost site. Epiphytic cover at site 1 was approximately 40% of the total leaf area while at site 2 it was 60% and at site 3 it was almost 80%.
Seagrass C:N results are given in Table 3. These values are in the same order of magnitude as those found by Hemminga et al. (1994) for Thalassodendron ciliatum growing in the Gazi Bay area in Kenya. It is interesting to note that C:N values were higher at the site closer to the mangrove forest and were lowest at the site farthest away from the forest. However, a slightly different picture emerged when C:N ratios were calculated on the basis of seagrasses and epiphytes put together. The C:N value at site 1 is dramatically reduced while those at the other two sites are increased (Table 3).

Table 3. C:N ratios of seagrasses and seagrasses with epiphyte cover at the different sites in the bay (±SD, n = 6)

<table>
<thead>
<tr>
<th></th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seagrass only</td>
<td>18.6 ± 3.3</td>
<td>14.5 ± 2.1</td>
<td>13.6 ± 1.6</td>
</tr>
<tr>
<td>Seagrass with epiphytes</td>
<td>15.9 ± 2.8</td>
<td>19.5 ± 3.4</td>
<td>17.0 ± 2.5</td>
</tr>
</tbody>
</table>

Export of mangrove carbon and nitrogen

Measurement taken on the mouth of the Mapopwe Creek revealed that there was, on average, higher concentration of total POM, TC and TN in the water ebbing from the mangrove forest (Figures 6 and 7) compared to the situation during flood tides. Moreover,
the C:N ratios of the sediments at the various sites were within the same range as that of the particulate matter in the water coming out of the forest during ebb tides (Table 1 and Figure 7). These data point to the fact that there is outwelling of mangrove-derived particulate matter and this material is possibly trapped in the seagrass area close to the mangrove forest. Apparently, the influence of mangrove outwelling is reduced with distance from the mangrove forest as shown by the progressive reduction of the concentration of both TOC and TN from site 1 to site 3.
DISCUSSION

Previous work in the mangrove lined creeks adjacent to the present study area have shown that the water flowing from the Mapopwe Creek has very low levels of dissolved inorganic nutrients (Mohammed and Johnstone, 1995). This includes dissolved ammonia and soluble reactive phosphorus which both exhibited high concentrations in the mangrove sediments (Mohammed and Johnstone, in press). As a result, it was concluded from these studies that dissolved inorganic nutrients are efficiently sequestered in the mangrove sediments by the combination of microbial production, microphytobenthic uptake, and possibly by denitrification. It was further proposed that, in view of the turbid waters that leave the mangroves every tidal cycle, any export occurring from the mangroves is likely to be as particulate organic matter (POM) or possibly as dissolved organic matter.

As an attempt to assess this possibility, the present study aimed to examine community metabolism and nutrient dynamics of the potential recipients for this POM with the intention of identifying any impact that it might have on nutrient dynamics or community production. As shown by Hemminga et al. (1994) for a similar ecosystem in Gazi Bay, Kenya, mangroves are capable of supplying POM to adjacent seagrass communities, although the spatial scale over which this happens may be limited. Further, the Gazi Bay study utilised δC13 values to infer changes in community metabolism resulting from the input of mangrove POM. The present study sought to examine whether such impacts could be measured in real-time.

In general terms, the seagrass meadows examined in this study exhibit a number of traits characteristic of many other seagrass communities. The levels of community production and above-surface biomass fall well within the range reported elsewhere for tropical seagrass meadows (e.g. review by Alongi, 1996). Similarly, seagrass communities tend to exhibit such a variety of species compositions that the communities in Chwaka Bay could not be described as unusual. However, personal observations along much of the coast of Tanzania suggest that the almost monoculture of *Enhalus acoroides* found in large areas of Chwaka Bay is uncommon.

Unlike mangrove detritus, detritus in seagrass meadows are limited in their ability to sequester nitrogen from detrital breakdown. Harrison (1989) in his review of seagrass detrital breakdown concluded that there is no net immobilisation of nitrogen during the decomposition of seagrass litter. In a study of the nutrient budget of the eelgrass, *Zostera marina*, Pedersen and Borum (1992) have shown that seagrass need an exogenous source of nitrogen to meet deficit, as losses do not balance. Eel grass has been shown to take up nitrogen from the water column and porewater through their leaves and roots (Caffrey and Kemp, 1990, 1992; Pedersen and Borum, 1993). Nitrogen deficit in seagrasses is also met through nitrogen fixation and sedimentation from the water column (Alongi, 1996). In the Chwaka Bay, benthic ammonia levels are significant but there is negligible efflux into the water column; rather, we see a variable but small uptake of all DIN. Blackburn et al. (1994) in a study of *Halodule beaudetti* beds in
Jamaica, have shown that anaerobic processes such as sulphate reduction, stimulated by roots exudates, play a major role in ammonia production. This could only be enhanced by external inputs from, for example, POM. At the same time, we know that the uptake by roots may be so strong as to hinder or prevent efflux from the sediments. This may be the case in the Chwaka Bay. As shown for Zostera marina beds, the uptake of N can occur via roots and leaves and that this represents approximately 73% of N available to the plants (Pedersen and Borum, 1993).

It should be noted, however, that some studies (e.g. Caffrey and Kemp, 1990) have shown benthic ammonification to produce more NH₄⁺ than required by the associated seagrasses. In Chwaka Bay, it appears that ammonium production supports a strong sediment pool but there is no release, as mentioned. Alternatively, this NH₄⁺ could be utilised by roots (as stated) or it could pass into microbial biomass, phytobenthos, nitrification and denitrification.

In Chwaka Bay, we have seen a considerable NOₓ pool which is variable in depth distribution, apparently due to animal activity as proposed from other areas (Aller, 1982; Aller and Yingst, 1985). Furthermore, studies on seagrasses have indicated an enhancement of nitrification due to oxygen supply related to dissolved oxygen translocation and release through the roots (Alongi, 1996). Again, however, a small NOₓ uptake was observed with chamber experiments, hence any excess production (above-root uptake) appears to be directly consumed by the sediment surface. Clearly, some of the NOₓ may be reduced again to NH₄⁺ as shown by Koike and Hattori (1978), although this could not be estimated in the present study. Alternatively, NOₓ can be denitrified. Caffrey and Kemp (1990) in their study of nitrogen transformation in North American seagrass beds, concluded that there was no coupling between nitrification and denitrification in Zostera beds, but these transformation processes were tightly coupled in Potamogeton perfoliatus beds. In Chwaka Bay seagrass communities, rates were low and not coupled.

As Table 2 shows, nitrification rates in the bay during light incubations varied from zero at site 1 to 12.0 μmol N/m²/h at site 2, while site 3 showed a rate of 6.0 μmol N/m²/h. On the other hand, denitrification rates were more or less similar at the three sites. Rates during light incubations were 1.3, 0.9 and 0.4 μmol N/m²/h at site 1, 2 and 3 respectively. The low nitrification rates in Chwaka Bay suggest that the seagrass communities in the bay rely on a supply of N from external sources. This N appears to be efficiently utilised within the seagrass communities as suggested by the low denitrification and flux rates.

Results from the present study indicate that the source of N for the seagrasses is from the particulate organic matter outwelling from the mangrove forest, which is presumably trapped within the adjacent seagrass zone outside the forest. This is evidenced both by the amount and quality of the POM being exported in tidal waters which shows export, and by the relatively higher TOC and TN levels at the site closest to the mangrove forest, which indicates trapping. The similarity in the range of C:N
values of the sediment in the seagrass zones and the particulate matter in the outwelling mangrove water also point to mangrove export and trapping by seagrasses. The question is whether this outwelling of POM and its subsequent trapping by the seagrasses has any effects on the productivity of the latter. The data obtained in this study show there are significant variations in the production levels of the seagrass communities at the three sites investigated. However, contrary to expectations, the highest production was observed not at the site that is a direct recipient of the exported mangrove carbon and nitrogen but at the site farthest away from the mangroves. This is despite the relatively lower sediment carbon and nitrogen content at this site (site 3). Consequently on the face of it, there is no obvious relationship between mangrove outwelled nutrients and seagrass production. The data also show that the seagrass communities closer to the forest are essentially heterotrophic while those at site 3 are autotrophic.

In their study in the Gazi Bay, Hemminga et al. (1995) were confronted with a more-or-less similar situation where they did not see any direct relationship between mangrove outwelling and leaf production and chemical characteristics of adjacent Thalassodendron ciliatum beds. They attributed this apparent anomaly to poor nutritional quality of the mangrove POC emanating from the forest and the stressful conditions under which the seagrasses closest to the mangrove forest grow, which mask the impact of nutrient input. In our study, the impacts of nutrient input and physical conditions were clearer. There was comparatively higher primary production at site 1 than at site 2 corresponding to higher sediment nitrogen and carbon at site 1, but both these sites showed lower net production compared to site 3. The variations in production between site 1 and 2 can therefore be attributed to differences in sediment nutrient variations between these two sites. Moreover, the variations in primary production between site 1 and 2, and that at site 3, can be attributed to the impact of physical factors on the seagrasses. As it has been mentioned above, the seagrass communities at these sites, and especially at site 1, grow in areas with high current velocities. This is reflected in the sediment distribution patterns at these sites. Consequently, production at these sites is possibly hampered by these severe conditions as observed by Hemminga et al. (1995) in Gazi Bay. Moreover, primary production at these sites may also be inhibited, especially during low tide, by low irradiance due to high sediment load in the water column (during the rainy seasons) and high irradiance (during the dry seasons). A one-time measurement of incident light at the surface of each site, on a partly cloudy day, gave a mean value of 1060 (± 159) µmol/m². This is well above the level of light saturation reported for seagrass species (Hillman et al., 1989). Accordingly, it should be noted that these sites are particularly shallow at low tide and so any impact that might result from mangrove input of nutrients may be masked by these factors. Compared to sites 1 and 2, seagrasses at site 3 are growing in a deeper, relatively calmer, and more oceanic environment. Hence they are more able to support a higher production.

However, other factors apparently account for higher primary production observed at site 3 despite low sediment nutrient levels. We observed that the seagrasses growing at this site have the highest epiphytic cover (80%) as compared to 40 and 60% for site
1 and 2 respectively. It has been proposed in many studies that epiphytes on seagrasses contribute a significant proportion of the total organic carbon production in seagrass communities (van Montfrans et al., 1984; Brouns and Heijst, 1986; Pollard and Kogure, 1993). For example, Heijst (1985, 1987) has shown that the contribution of the epiphytic component in the annual mean above-ground production was 33 and 44%. Kitting et al. (1984) concluded that primary production of epiphytic algae could parallel that of the seagrasses, per blade or per unit biomass. Moreover, we did not observe in this study any consistent relation between sediment C:N values and seagrass production (mangrove outwelling and production)—in fact there was an inverse relationship between seagrass C:N values and those of sediments. Also there were no significant differences in the levels of sediment nutrient processes (nitrification and denitrification) that would have caused spatial differences in sediment nutrient characteristics among sites. These data point to the fact that sediment nutrients do not directly account for the observed variations in productivity, at least the high primary production observed at site 3. Whilst the seagrasses themselves take a significant proportion of their nutrient requirements from the sediment (Short and McRoy, 1984; Blackburn et al., 1994; Erftemeijer and Middleburg, 1995; Hemminga et al., 1995), epiphytic communities are more directly dependent on water column nutrient supply. Consequently the high production observed at site 3 is probably due to the epiphytes rather than the seagrasses. Apparently the nutrients export from the mangroves is not directly coupled to primary production at this site.

We conclude from the above discussion that the Chwaka mangrove forest exports POM to the adjacent seagrass communities through the Mapopwe Creek; the influence of the mangrove outwelling is, however, restricted to the seagrasses areas close to the forest. Apparently the influence of mangrove outwelling tapers off by the time the mangrove water reaches the third site. This entrapment of mangrove POM by the seagrasses closer to the mangroves is possibly enhanced by the presence of the limestone sill near the entrance of the Mapopwe Creek which hinders effective water exchange between the mangrove forest and the open bay. This differential mangrove POM input and possibly the severe conditions under which they grow has rendered the communities closer to the forest more heterotrophic while those at the site farthest away from the forest more autotrophic. It must be emphasised here that this work and the previous one (Mohammed and Johnstone, 1995) only looked at the dissolved inorganic and particulate nutrient fractions. The dynamics and influence of dissolved organic fractions remain to be investigated—this is the subject of another study.

REFERENCES


A note on leaf litter degradation, and nitrogen and carbon release in species from three families of mangroves in Zanzibar

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ABSTRACT

Leaf litter production from mangrove forests is the largest source of input of materials into inshore ecosystems on many tropical coasts and is an important source of nutrients. There have been no previous field experiments reported from East Africa and work from elsewhere has not emphasised the systematic position of the experimental species. In this study the degradation rates and release of carbon and nitrogen of three families of mangroves, Avicenniaceae (\textit{Avicennia marina}), Sonneratiaceae (\textit{Sonneratia alba}) and Rhizophoraceae (\textit{Ceriops tagal}) are reported. Significant differences occurred between the species. \textit{Avicennia} and \textit{Sonneratia} decayed rapidly, with 80–90\% loss within four weeks. In contrast, \textit{Ceriops} lost only 30\% biomass in the same period. Samples were also analysed for changes in total carbon and nitrogen during decomposition. Carbon increased in all species during the first seven days and then decreased, while nitrogen levels remained almost constant throughout. The C:N ratio was almost constant in \textit{Avicennia} and \textit{Sonneratia} at ca 50:1 but was more variable in \textit{Ceriops}, increasing from 80:1 to 160:1 in the first week of decomposition, before falling to 100:1.

INTRODUCTION

Leaf litter production in mangrove communities is an important source of food materials for a wide variety of organisms, including commercially exploited invertebrates and fishes. It is particularly important as a source of organic material in tropical estuaries, (see Wafar et al., 1997 for a recent review). The three species studied here, \textit{Sonneratia alba} J. Smith, \textit{Avicennia marina} (Forsk.) Vierh., and \textit{Ceriops tagal} (Perr.) C.B. Robinson produce ca 18, 11 and 7 tonnes/ha/yr respectively (Shunula and Whittick, 1999).

The decomposition of plant litter depends on fragmentation by invertebrates, leaching of water-soluble substances and microbial utilisation of both particulate and dissolved organic matter (Tam et al., 1990; Pelegri et al., 1997). The rate of decomposition, and nutrient release, are partially functions of the composition of the leaf material. The presence of high concentrations of antibiotic tannins in mangrove leaves

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delays their colonisation by microorganisms and the low decomposition rates in the Rhizophoraceae have been attributed to these chemicals (Cundel et al., 1979; Robertson, 1988).

This study examines the rate of leaf litter decomposition and the changes in abundance of carbon and nitrogen during this process for three species of mangrove belonging to three different families of plants, namely S. alba (Sonneratiaceae), A. marina (Avicenniaceae) and C. tagal (Rhizophoraceae) under similar environmental conditions.

MATERIALS AND METHODS

The method recommended by Snedaker & Snedaker (1984), as part of the UNESCO-IBP methodologies, was used to determine the rate of leaf decomposition. Yellow senescent leaves of S. alba, C. tagal and A. marina, were collected prior to abscission and cleaned with a soft cloth to remove adhering debris. Decomposition bags measuring 20x30cm of 2.5cm mesh size were divided into five longitudinal strips with nylon thread. Five to ten leaves of each species were weighed and one or two placed in each bag section to prevent any overlapping of the leaves during decomposition. The bags were then stitched closed. Seventy bags for each of the three mangrove species were prepared in this manner. The bags were then attached at intervals on a nylon line to prevent overlap and placed on the forest floor in a tide pool area at Maruhubi, on the west coast of Zanzibar. Ten bags of each species were recovered from the line at 7-day intervals until decomposition was completed, or all bags had been removed. The contents of each bag were removed and gently cleaned of adhering debris before drying to constant weight at 70°C.

Prior determination of a relationship between fresh and dry weight had been carried out on over 100 samples of leaf weights for each mangrove species, by oven-drying leaf lots of known fresh weight. This provided an average conversion factor of 0.38 for A. marina, 0.34 for C. tagal and 0.15 for S. alba. These were then used to calculate the original dry weight of the leaf samples prior to decomposition.

For carbon/nitrogen analysis the oven dried material from each of the 7 day recovery intervals was milled into powder, and replicate aliquots were analysed using a Carlo Erba model 1106 elemental analyser using acetonilide as a reference standard.

RESULTS

The results of the leaf litter degradation experiments are shown in Figures 1–3, as the mean values (n=10) and 95% confidence intervals. Ceriops tagal was the most refractory, while S. alba and A. marina decomposed the most readily. Avicennia marina lost approximately 40% of its initial weight within 14 days and had lost more than 80% at 42 days, while S. alba lost 75% in the same period. At 72 days, the end of the experiments, the leaves of S. alba and A. marina had lost 95% of their original mass while
Figures 1–3. Decomposition of *Avicennia marina*, *Ceriops tagal* and *Sonneratia alba* over a 70-day period. Means (n=10) and 95% confidence limits

Figures 4–6. Carbon and nitrogen levels in decomposing leaves of *Avicennia marina*, *Ceriops tagal* and *Sonneratia alba* over a 35-day period. Mean of two replicates
over 60% of the *C. tagal* leaves remained.

The carbon and nitrogen content of the leaves during the first 35 days of decomposition are shown in Figures 4–6 as means of two replicate samples, the differences between replicates in all samples were less than 5% of the mean and no error bars are presented. Initially all showed ca 30% carbon, but the nitrogen content varied, being highest in *A. marina* at 0.8% and lowest in *C. tagal* at 0.4%. All species showed a rise in carbon in the first seven days, which then declined. The nitrogen content showed little change and remained at similar levels throughout the experiment. The C:N ratios are plotted in Figure 7. For *A. marina* and *S. alba* they remained at ca 40–60, whereas in *C. tagal* the ratio doubled from 80 to 160 in the first seven days and then declined.

![Figure 7. Carbon/nitrogen ratio in decomposing leaves of *Avicennia marina*, *Ceriops tagal* and *Sonneratia alba* over a 35-day period](image)

**DISCUSSION**

Most of the energy from primary production in mangroves becomes available to support consumer production only after it has been processed through decomposer pathways. The decomposition of mangrove leaf litter is therefore a significant step in the mangrove ecosystem related food chains. The decomposition may also make inorganic nutrients available for re-use by the mangroves. Ecologically, the most refractory leaves can be
moved by ocean currents to distant places before decomposition fully sets in, thus they may be partly responsible for supplying nutrients to ecosystems away from the litter source (Slim et al., 1996).

There are some major differences in the rate of leaf decomposition of the different species. *Sonneratia alba* leaves were shown to be the fastest to decompose, followed by those of *A. marina*, while *C. tagal* was most refractory. These observations compare well with those of Steinke and Ward (1987), who observed a loss in weight of 57% in *A. marina* leaf litter in three weeks. In the current study, leaves of the same species lost 41% of their original weight in three weeks. Steinke and Ward (1987) also observed a faster rate of degradation in *A. marina* compared to *Bruguiera gymnorrhiza*, another member of the Rhizophoraceae, under permanent submergence. Robertson (1988) showed that *C. tagal* in Australia decayed at half the rate of *A. marina*, while Wafar et al. (1997) found similar rates in *A. officinalis*, which decayed at twice the rate of Rhizophora. While other factors are undoubtedly important, these rates of decay can be interpreted by reference to leaf tannin levels. Tannin levels are higher in the leaves of the Rhizophoraceae ca 12% for *C. tagal* compared to 7% for *A. marina* and 5% for *S. alba* (Robertson, 1988), and this may account for more rapid degradation of these latter species.

The leaves of *A. marina* initially contained almost twice the concentration of nitrogen as *C. tagal* and this is in agreement with data from other members of the Rhizophoraceae (Pelegrí et al., 1997; Wafar et al., 1997). After the initial nitrogen loss attributed to leaching, other workers have shown a subsequent increase and explained this result by the colonisation of the leaves by nitrogen-rich microorganisms including those capable of nitrogen fixation (Gotto et al., 1981; Rice and Tenmore, 1981; Pelegrí et al., 1997). However, in this study the increase was minimal and this aspect clearly needs further study, with regard to local species and conditions. The changes in carbon after the first week of sampling are more consistent with these other studies, though the increase in carbon level in *C. tagal* in the first week is unusual and also needs further study.

The C/N ratios of the decomposing leaves showed little differences between *S. alba* and *A. marina*. *Ceriops tagal* had a much greater C/N ratio at all stages of decomposition, which is in agreement with other work (Cundel et al., 1979; Pelegrí et al., 1997; Rice and Tenmore, 1981). However in this study these changes are attributable to a decrease in carbon rather than an increase in nitrogen, and this aspect also warrants further study.

**ACKNOWLEDGEMENTS**

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Identifying the benthic microbial community structure using a molecular technique

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ABSTRACT

The practice of open water macroalgal cultivation and tourism-related activities are adding new pressures to the coastal and marine environment of Tanzania. New molecular techniques facilitate the identification of possible changes in microbial diversity and community in the marine environment. One of these techniques, in situ hybridisation with fluorescence labelled rRNA-targeted nucleic acid probes (FISH), was used in a pilot study to determine possible changes in benthic bacterial community within seaweed farms on Zanzibar. Sulphate reducing bacteria were detected using specific probes against 16S rRNA. The potential of this technique and results from a pilot study are discussed.

INTRODUCTION

Like most coastal areas, the coastal areas of Tanzania are the centres of economic growth. However, the combination of a rapidly growing population and a poor understanding and management of resources has resulted in a number of environmental problems in some coastal areas of Tanzania. Of these problems, the main ones are over-exploitation of resources and a loss of coastal and marine biodiversity (Moffat et al., 1999). In addition, the recent development of seaweed farming and tourism is adding new pressures to the coastal and marine environment. Hence, monitoring the potential impact of these human activities on the coastal ecosystem and its biodiversity, is essential. Changes in the benthic microbial community structure are often early indications of changes in the marine environment (Zehnder and Stumm, 1988). Bacteria are the primary decomposers of dead organic matter and play an important role in the food webs and nutrient cycling. In studies of the effects of management and pollution on the structure and function of ecosystems, reliable estimates of microbial numbers and activity are important. The identification of possible changes in microbial diversity in the marine environment has been limited, as most bacteria cannot be cultivated and are therefore difficult to identify. Various new molecular techniques, however, now
make it possible to describe the microbial diversity. One of these techniques, *in situ* hybridisation with fluorescent nucleic acid probes, FISH, was used in a pilot study in order to determine potential changes in the benthic bacterial community within seaweed farms on Zanzibar.

Seaweed has been described as one of the major positive contributions of the private sector to Tanzania’s economy, in terms of introduction, promotion and development (Vice-Chancellor of the University of Namibia, Professor Keto Mshigeni). The crop was introduced for the first time in Zanzibar in 1989 (Mtolera et al., 1996; Msuya, 1995). Since then, the cultivation of the seaweed in lagoons, along the East coast of Unguja Island and at a number of locations along the coasts of the mainland of Tanzania, has increased rapidly. Farmers in most areas are earning an average of Tsh. 50,000 per month from the crop. Foreign income from the crop increased from US dollars 8.8 in 1994 to US dollars 20M in 1997 (Merere, 1999). The alga is grown above the benthos in intertidal zones off beaches and in shallow lagoons. Most of the seaweed farmers are women, and consequently, the income derived remains largely under the control of the women. Interestingly, this has resulted in changed socioeconomic patterns in the villages (Eklund and Petersen, 1992; Msuya, 1995).

Considering that seaweed farming is an extensive activity, and that it is government policy to encourage this activity, it is important to monitor its possible impact on the lagoonal ecosystem. Therefore, the marine microbial project aims to investigate possible changes within the benthic microbial ecology and biodiversity of this environment using the molecular technique FISH together with conventional nutrient analysis. The following text first briefly describes the principle of the FISH technique, then presents the results of a pilot study where the abundance of sulphate reducers in seaweed farms was detected using FISH.

**FLUORESCENT IN SITU HYBRIDISATION (FISH)**

Fluorescent *in situ* hybridisation (FISH) is a powerful technique which allows for the identification of individual microbial cells in their natural habitat (for review see Amann et al., 1995). The technique relies on the specific hybridisation of the nucleic acid probes to the naturally amplified intracellular ribosomal RNA. The two larger ribosomal RNA molecules of bacteria, 16S rRNA and 23S rRNA, both contain regions of high evolutionary conservation. Consequently, comparative analysis of rRNA sequences can identify the so-called ‘signature nucleotide motifs’ on various taxonomic levels that are suitable targets for an evolutionary-based identification (Wagner et al., 1995). Hybridisation techniques used for this purpose rely on the specific binding of single stranded nucleic acid probes complementary to such conserved signature regions on the rRNA.

Oligonucleotide probes are convenient tools for many areas of microbial ecology since they can monitor specific populations in environmental samples based on constant genotype features and not on variable phenotypic features like morphology. Today, more
than 50% of the cells in an environmental sample can be identified with improved fluorescent
dyes. This applies even to oligotrophic marine samples in which the visualisation of small
cells with low numbers of ribosomes has previously been problematic. This compares
favourably with the usually less than 1% of microorganisms that can be characterised
using cultivation-dependent methods (Amann et al., 1997).

Most probes are designed and synthesised chemically as oligonucleotides with a
length of 15–25 nucleotides. Large quantities of oligonucleotides can rapidly and
inexpensively be produced at high quality by solid phase synthesis. Various marker or
linker molecules can be added to the probe. The design of rRNA targeted probes is
performed in a computer assisted fashion using a rRNA database. The designed sequence
is evaluated by the computer programme and chemically synthesised as a probe (Glöckner
et al., 1996; Amann et al., 1997). Following synthesis, the probe is further evaluated
experimentally on selected target and non-target bacteria.

The principle of in situ hybridisation with fluorescence labelled, rRNA-targeted oligo-
deoxyribonucleotide is quite straightforward. First, the morphology of the sampled cells is
stabilised and the cell walls and membranes are made permeable for the penetration of
the probes. This is achieved by the addition of fixatives, based on aldehydes or alcohols,
to the sediment sample (Glöckner et al., 1996). Subsequently, the probes are applied in
an adequate hybridisation buffer and incubated at a suitable temperature, which varies
for different cells. Washing steps remove unbound and part of the non-specifically bound
fluorescent probe. The sample is subsequently analysed by epifluorescence microscopy
or CCD camera.

APPLICATION OF FISH: A PILOT STUDY IDENTIFYING BENTHIC
BACTERIA IN SEAWEED CULTIVATED AREAS IN TANZANIA

The FISH technique was applied in a pilot study of benthic bacteria from lagoons along the
east coast of Zanzibar in order to monitor the diversity and spatial distribution of the
benthic microbial community within coastal areas exposed to commercial seaweed
cultivation. The study included villages along the east coast of Zanzibar and the villages
Lindi and Mnete, close to Mtwarra in the south of Tanzania mainland. In Mnete, seaweed
farming had not commenced in June 1998, although the area was prepared for farming.
The intention is to monitor the benthic bacterial community structure in Mnete as the
farming progresses. The project focused on the sulphate reducing bacteria that are essential
components of the microbially mediated nutrient dynamics in the sediment and important
in relation to the oxidation of organic matter and redox-state in the sediment. The total
amount of benthic bacteria and the presence of sulphate reducers were analysed within
farmed and non-farmed areas using in situ hybridisation with different fluorescent probes.
The probes that are used are designed to target 16S rRNA. A universal probe that detects
all bacteria was used for determining total bacteria. In order to investigate the presence
of sulphate reducers, a specific probe was used.
RESULTS

Normally, depending on habitat, 60–100% of the DAPI (4′6-diamidino-2-phenylindole)-detectable cells (both living and dead cells) are identified with the universal probe and about 20% are detected with the specific probe for sulphate reducers (Sjöling, unpublished). This means that normally 20% of the total bacterial population consists of sulphate reducers. Results of in situ hybridisation analysis of sediment samples from the lagoon outside different villages showed no significant differences in total bacterial abundance between the farmed and non-farmed areas. The abundance of sulphate reducers, however, was reduced by 30–70% within the farmed area both in Paje and Nungwi. This is in accordance with our previous study (Sjöling and Johnstone, submitted manuscript) showing that the rate of sulphate reduction was reduced within the seaweed farms of Paje. In Mnete, FISH analysis showed that there was no difference in the abundance of sulphate reducers between the sites. This result was expected as the algal cultivation had not commenced at the time of sampling. Results of the pilot study, together with other studies (Johnstone and Oláfsson, 1995), indicate that the seaweed farming is affecting the activity of benthic bacteria. Previous mesocosm experiments in the laboratory, however, show that rates of sulphate reduction are not affected by the addition of alga to the mesocosm (Johnstone and Oláfsson, 1995; Sjöling and Johnstone, submitted manuscript). In addition, organic content, POC (particulate organic carbon), PON (particulate organic nitrogen), protein, humic substances and grain size, were analysed; however, these did not vary between the sites (Sjöling and Johnstone, submitted manuscript). Therefore, it is possible that the alga mechanically disturbs the sediment, and the habitat of the benthic bacteria, resulting in a decrease of their essential activity. Interestingly, studies of meiofauna have shown that some species are in lower abundance in seaweed farms compared to non-farmed areas (Oláfsson et al., 1995).

CONCLUSIONS

Considering that results from the pilot study using FISH analysis show that there is a decrease of sulphate reducers in the benthos in areas with seaweed farms, further studies are required to investigate any potential affect it may have on the lagoonal ecosystem. The pilot study, together with several other studies, clearly demonstrates the potential of the fluorescent in situ hybridisation (FISH) technique for studies of microbial population. The detection and identification of bacterial species using traditional biochemical methods is labour-intensive and time consuming and can also be less specific. Furthermore, few of the environmental bacteria are cultivable. The FISH method, however, can be used to rapidly identify and detect even uncultivable bacteria at very low numbers in a few hours and is therefore a suitable method for the identification of most bacteria in the environment. In addition, once the probes have been synthesised, the only requirement, apart from normal laboratory equipment, is an epifluorescence microscope.
FUTURE PERSPECTIVES

The intention is to use the FISH technique for further analysis of possible changes in benthic bacterial community in seaweed farms and also in mangrove deforested areas along the coast of Tanzania. Bacteria, especially sulphate reducers and ammonia oxidisers, together with archaea, will be identified and monitored using FISH. Results will be cross-calibrated with nutrient analysis and will be used to relate the abundance and activity of the benthic bacteria to in situ nutrient concentrations and bioavailability. Such studies will yield new insights into the true abundance of well-known or new bacteria and increase our knowledge of the microbial ecology of these interesting ecosystems. The aim is also to obtain results that may contribute to the management of open-water seaweed cultivation, and to outline an ecosystem approach for evaluation of mangrove restoration initiatives.

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The marine biodiversity of the western Indian Ocean and its biogeography: How much do we know?

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ABSTRACT

Prior to the 1960s the biota of the western Indian Ocean inshore marine habitats received scant attention from taxonomists resulting in a poorly known flora and fauna. Fortunately, over the last 40 years there have been considerable developments in the study of marine biodiversity in this region, both from regional scientists and by those based at institutions in Europe and elsewhere. This paper reviews the current status of taxonomic knowledge of the marine biodiversity of the western Indian Ocean, focusing on the macroflora and macrofauna of the intertidal and shallow subtidal environments. The taxonomy of many of the smaller and particularly the softer-bodied invertebrate taxa remains a challenge to specialists, and as a result these taxa continue to be inadequately known from this region. Such groups include sponges, ctenophores, octocorals, polychaetes and tunicates. There is however, considerably greater knowledge on the taxonomy and diversity of groups such as coastal plants, mangroves, seagrasses, macroalgae, scleractinian corals, most crustacean taxa, molluscs, echinoderms, fishes, reptiles and marine mammals. For some of these groups this paper provides an examination of their possible origins, the levels of regional endemism and compares their diversity with that of other provinces of the Indo-Pacific for which similar knowledge is available. Finally, the importance of continued taxonomic research in the region is discussed, in light of the current threats to marine biodiversity, and the need to make the information which is currently available on the western Indian Ocean marine diversity more accessible to decision makers and to the public in general.

INTRODUCTION

At the turn of the century Gardiner (1907) stated that “… of all oceanic areas none seems so little known in 1905 as that between India and Madagascar”. He then led the Percy Sladen Trust Expedition with H.M.S. Sealark for 6 months, visiting mainly the western Indian Ocean islands, including Madagascar, from which numerous reports were produced.
Despite these reports and those of later expeditions, in his landmark treatise of marine zoogeography of the world, Ekman (1953) acknowledged that the “northern and western parts of the Indian Ocean are on the whole not so systematically investigated that their zoogeographical position can be determined”. More poignantly Salm (1995) recently stated that “not only are we unaware of the extent of our biological wealth, but also of the rate at which we are losing it”.

Fortunately, in the last 40 years various taxonomic groups have received attention, resulting in a considerable growth of information (see Macnae and Kalk, 1958; Branch et al., 1994; Kalk, 1995). A Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands (Richmond, 1997) provides a recent, brief and concise summary of the many taxa which contribute to the diversity of flora and fauna of the shores and shallow seas of the region. In this text over 1600 species are described and illustrated, and the many confusing synonyms which plague some of the taxa (e.g. molluscs and echinoderms) are revised. Though this work is by no means complete, it provides for most taxa, for the first time, a brief examination of marine species diversity as well as a basis for continued documentation of marine taxa for the region.

The purpose of this paper is to compile the information from Richmond (1997), extending further the discussion for the various taxonomic groups and highlighting groups where more research is required. The focus is on the taxa present in the intertidal and shallow subtidal waters of the western Indian Ocean. The diversity and biogeography of the Polychaeta, Mollusca and Echinodermata were also examined in more detail by Richmond (1999) and a summary of those findings is incorporated.

MEASURING BIODIVERSITY

The definition of and methods used to measure biodiversity have been an area of considerable controversy. The definition employed by the Convention on Biodiversity (Article 2), UNCED 1992 is as follows: Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems. Unfortunately, the Convention does not assist in defining how to measure biodiversity. Nevertheless, there is a need to quantify biodiversity in some way, so that changes over time can be monitored, locations of change determined and ways of maintaining it considered.

Commonly used measures of biodiversity include: (a) higher taxonomic levels, such as order or family, which have been shown to increase with species richness (Gaston and Williams, 1993); (b) phylogenetic diversity, which reflects the closeness of species in evolutionary terms, capturing the degree of relationship and the degree of difference in many other characteristics; (c) species richness referring simply to the total number of species, and (d) species richness combined with numbers of each species (occurrence) thus giving a more balanced measure of the overall diversity. In
practice it is the measure of species richness which is used most often to reflect biodiversity. Reasons for using this simple measure include the fact that species richness is positively correlated with number of higher taxa and character richness (Roy et al., 1996; Williams and Humphries, 1996) and it is therefore a good 'surrogate measure' (Gaston and Spicer, 1998). Species richness is also frequently measurable with ease and significant information already exists in the literature, in museums and other documentation agencies.

**APPROACH AND METHODS**

Between January 1992 and October 1997 work on the preparation of *A Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands* was conducted primarily from a base at the Institute of Marine Sciences, (University of Dar es Salaam) on Zanzibar. The area considered as the western Indian Ocean extends from southern Somalia to the Natal coast of South Africa, embracing the islands of Madagascar, Comoros, Réunion, Mauritius and the Seychelles. Visits were made to most parts of the region to conduct brief field surveys, liaise with regional specialists and examine taxonomic collections. Sites visited included: Watamu and Mombasa (Kenya), Mafia and Pemba islands (Tanzania), Inhaca Island (Mozambique), northern Natal (South Africa), Tulear (SW Madagascar), Nose Be (NW Madagascar), Moroni (Comoros) and the La Digue and Mahe islands (Seychelles). In addition, quantitative sampling of soft substratum benthic surveys were conducted in Zanzibar (Tanzania). For comparison purposes detailed ecological surveys were also conducted in eastern Saudi Arabia (Arabian Gulf) and brief field surveys were conducted in western Saudi Arabia (Red Sea) and more recently SE Papua New Guinea (Solomon Sea/Coral Sea).

Material for each taxonomic group was collected and catalogued in Zanzibar. Where necessary specimens were deposited or exchanged with specialists from other institutions, many of which provided assistance with collection and identification. Of these, 48 specialists contributed directly to the guide book with chapters on their specialty.

The phyla Polychaeta, Mollusca and Echinodermata were subsequently examined in greater detail by Richmond (1999). A collection of polychaetes from Zanzibar and Mafia were identified and their wider distribution established from the literature. A preliminary species checklist of molluscs was prepared based on material collected, records from 72 publications and reports dating from 1932 to 1997, unpublished collection lists and the species list of the material held by the National Museum of Wales. The latter museum holds the Melvill-Tomlin collection which includes many species from Mauritius as well as other parts of the western Indian Ocean. An echinoderm faunal checklist was compiled for the western Indian Ocean using data from 53 sources. Records were included only for species which were reported from depths shallower than 100m. The checklist also includes species records from numerous provinces within the entire Indo-Pacific region as well as the eastern Pacific and Atlantic Ocean, thus allowing for a biogeographical analysis of the western Indian Ocean echinoderm fauna.
STATUS OF KNOWLEDGE

A summary from the various taxonomic sections in Richmond (1997, 1999) allows an estimate of the overall species richness of the taxa in the region to be ascertained (see Table 1). The figures from Table 1 when represented graphically permit the contribution of each taxon to be visualised with ease (Figure 1). A cautionary note is that, as with all taxonomic studies, continuous progress is underway to elucidate confusing species, synonyms and describe new species, thus any findings are automatically outdated the moment they are put to paper.

The marine macro-taux occurring in the intertidal and shallow seas of the western Indian Ocean comprise an estimated minimum of 10,992 species. The Mollusca and the Pisces represent about half of the entire marine biodiversity of the region, with a clear domination by molluscs. Within the Mollusca the class Prosobranchia is the most

Table 1. Summary of the minimum estimated species number for major macroflora and macrofauna taxa from littoral and shallow sublittoral waters of the western Indian Ocean. Data from Richmond (1997) unless indicated

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Minimum no. of species</th>
<th>Taxa</th>
<th>Minimum no. of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangroves</td>
<td>10</td>
<td>Caridea</td>
<td>150</td>
</tr>
<tr>
<td>Seagrasses</td>
<td>12</td>
<td>Palinura</td>
<td>20</td>
</tr>
<tr>
<td>Macroalgae¹</td>
<td>1011</td>
<td>Thalassinidea</td>
<td>20</td>
</tr>
<tr>
<td>Porifera²</td>
<td>200</td>
<td>Anomura</td>
<td>50</td>
</tr>
<tr>
<td>Ctenophora</td>
<td>20</td>
<td>Brachyura</td>
<td>465</td>
</tr>
<tr>
<td>Scyphozoa³</td>
<td>30</td>
<td>Scaphopoda</td>
<td>10</td>
</tr>
<tr>
<td>Hydrozoa</td>
<td>100</td>
<td>Polyplacophora⁴</td>
<td>39</td>
</tr>
<tr>
<td>Octocorallia</td>
<td>300</td>
<td>Prosobranchia⁴</td>
<td>2550</td>
</tr>
<tr>
<td>Ceriantharia</td>
<td>20</td>
<td>Opisthobranchia⁵</td>
<td>400</td>
</tr>
<tr>
<td>Actiniaria</td>
<td>30</td>
<td>Pulmonata</td>
<td>20</td>
</tr>
<tr>
<td>Corallimorpharia</td>
<td>10</td>
<td>Bivalvia⁴</td>
<td>667</td>
</tr>
<tr>
<td>Zoanthidea</td>
<td>5</td>
<td>Cephalopoda</td>
<td>20</td>
</tr>
<tr>
<td>Scleractinia</td>
<td>200</td>
<td>Echinoida⁴</td>
<td>62</td>
</tr>
<tr>
<td>Antipatharia</td>
<td>10</td>
<td>Holothuroidea⁴</td>
<td>148</td>
</tr>
<tr>
<td>Platyhelminthes</td>
<td>100</td>
<td>Asteroida⁴</td>
<td>58</td>
</tr>
<tr>
<td>Echiura</td>
<td>22</td>
<td>Ophiuroidea⁴</td>
<td>132</td>
</tr>
<tr>
<td>Sipuncula</td>
<td>50</td>
<td>Crinoidea⁴</td>
<td>19</td>
</tr>
<tr>
<td>Polychaeta⁴</td>
<td>300</td>
<td>Phoronida</td>
<td>5</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>10</td>
<td>Brachiopoda</td>
<td>5</td>
</tr>
<tr>
<td>Cirripedia</td>
<td>30</td>
<td>Bryozoa</td>
<td>500</td>
</tr>
<tr>
<td>Nemertea</td>
<td>59</td>
<td>Hemichordata</td>
<td>20</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>300</td>
<td>Chaetognatha</td>
<td>50</td>
</tr>
<tr>
<td>Isopoda</td>
<td>100</td>
<td>Thaliacea</td>
<td>30</td>
</tr>
<tr>
<td>Stomatopoda</td>
<td>30</td>
<td>Asciacea⁶</td>
<td>100</td>
</tr>
<tr>
<td>Dendrobranchiata</td>
<td>10</td>
<td>Pisces</td>
<td>2000</td>
</tr>
</tbody>
</table>

Total 10,992

¹ Silva et al. (1996) (excluding South Africa); ² Van Soest, 1994 (including Red Sea and Arabian Sea); ³ Cornelius (pers. commun.); ⁴ Richmond (1999); ⁵ Yonow (pers. commun.); ⁶ Monniot (pers. commun. estimate for Mozambique).
species-rich taxon. For many taxa the figures can be largely regarded as conservative estimates of the true diversity of species for the region, as will be discussed below for the major taxonomic groups. In a study of the Hawaiian marine diversity Paulay (1997) found similar proportions among the taxa, with a total of over 7000 species recorded from those islands. Molluscs comprised about 20% of the total species number, though Paulay's study excluded fish and macroalgae, but included such groups as Nematoda and Protista which are excluded from the present study.

The botanical groups
Although mangroves and seagrasses are the basis of entire habitats, of extremely high importance ecologically and economically, these groups are represented by few species which are well known and accurately described (see Macnae, 1968 and Phillips and Meñez, 1988). Consequently their geographical distribution is also reasonably established. Though macroalgae are far more numerous in terms of species numbers, they too benefit from a reasonably ample and accurate literature. Nevertheless, new species from the region continue to be described (e.g. Coppejans et al., this volume). Very little can be said at present for the distribution and species abundance of macroalgae, given the lack of comparative studies; however, research in this field is ongoing, a situation which applies equally to the tropical Pacific (see Abbott, 1995).
Porifera
Current accurate estimates for the diversity of the Porifera in the western Indian Ocean are not available, though Kelly-Borges (1997) estimates there could be ‘several hundred’ species but that further work is required to determine a closer approximation. Van Soest (1994) describes a total of 683 species (in this case including the Red Sea and Arabian Sea) and found 411 Demospongiae that the western Indian Ocean associates closely with the Malay-Indonesia area where a total of 965 species are reported. He suggests that for widespread genera (13% of the total examined) their distributions are probably determined by historical and large-scale geographic factors such as tectonic events and barriers associated with deep water, temperature and continental run-off. Kelly-Borges and DeFelice (in press) found that for sponge fauna in Hawaii, the presence of ‘cosmopolitan’ species (i.e. of worldwide distribution) has masked the true diversity of that fauna and following detailed examination some of the taxa have been shown to include more species. This likely applies for the western Indian Ocean where the taxa described in the early literature are in need of extensive revision (Kelly-Borges, 1997).

Coelenterata
There are only an estimated 150 species of scyphozoans (jellyfishes) in the world, with about 30 species reported and collected from the region (Cornelius, 1997). A new species for the region was added to the records this year (Cornelius, pers. commun.) from a specimen collected at Mafia Island, Tanzania, during a 5-day collecting visit. This demonstrates that as more scientists become aware of the paucity of information on the group, the reported diversity is likely to increase slightly.

In general, hydrozoans have not been well studied throughout the western Indian Ocean though a number of localised investigations have been conducted which serve to describe the scale of this group. Two studies from the Seychelles revealed 88 species (Millard and Bouillon, 1973, 1975). Comprehensive investigations in southern Africa report a total of about 286 species (Branch et al., 1994).

Within the class Anthozoa, the Octocorallia are a large and taxonomically complex group with only a few specialists qualified to determine many of the species. As a result, only very rough estimates on the diversity within the region can be made at present. Schleyer (1997a) estimates there could be a few hundred species in the region. The Hexacorallia are in general better known though the anemone orders Ceriantharia and Actiniaria do require further research to elucidate many taxonomic uncertainties which continue to exist (see den Hartog, 1997). The order Scleractinia has received perhaps the greatest attention within the phylum, with numerous papers from various parts of the western Indian Ocean describing the taxa and the ecology of this important reef-building group. Sheppard (1987) reports 439 species of scleractinian corals from the entire Indian Ocean with 47 species (approx. 11%) endemic to the region. Schleyer (1997b) reports on approximately 200 species from the western Indian Ocean alone. It appears that these are relatively homogeneously distributed in the region and that unlike the Pacific Ocean,
the Indian Ocean does not reveal a pattern of decreasing concentric coral diversity levels radiating from the Malay-Indonesian region (Sheppard, 1998). What is found instead is a band of high diversity stretching across the Indian Ocean, as proposed by Rosen (1971), with about half of the corals widespread (from and including the Red Sea to South Africa and the western coasts of Australia and Malaysia), with only a few genera limited to the western extremes. New species do however continue to be described (e.g. Riegler, 1995).

**Polychaeta**

A recent collection of polychaetes from intertidal soft-substrates on Zanzibar and Mafia islands revealed 91 species with 29% found to occur at localities as far as the western Pacific, reflecting the occurrence of a widespread Indo-Pacific fauna (Richmond, 1999). An additional 22% of the collection were regarded as 'cosmopolitan'. No accurate estimate of the overall diversity of polychaetes of this region has been achieved to date, though a tentative, minimum estimate can be attempted by incorporating other studies, in particular those of Hughes and Gamble (1977) and Hove (1994). Such an analysis results in an estimate of between 300 and 500 species from the intertidal to the shallow subtidal.

Unfortunately, polychaeta taxonomy suffers from the lack of precise and thorough descriptions of the species in the early literature, combined with inadequately preserved and catalogued type specimens. Ciaparède (1867) for example, was firm in his belief that studies on preserved specimens were "positively useless, and that the Annelida can only be well studied at the seaside and by means of living individuals"! A further problem faced by taxonomists is the use of 'out of area' reference material. As Mackie (1996) explains, the use of taxonomic keys which were designed for one particular area (e.g. Day, 1967 for southern African taxa) when used in other areas, i.e. can result in erroneous identifications. For example, the use of Day (1967) to identify a specimen from Europe may result in a new record of that species outside of the southern Africa region. When the description of the southern African species is expanded to accommodate the European one, this then represents the first step to that species becoming 'cosmopolitan'.

Any study is likely to provide new species depending on the level of investigation. In the Arabian Gulf for example, a study by a single experienced polychaete taxonomist found 61 genera from 23 families with 23 new species records and 8 new genera records for that area (Fiege, 1992). He also found that of the total entities recorded, only 45 could be positively identified to species level, reflecting the widespread lack of a thorough knowledge of this taxon. The study by Fiege (1992) is an example of the 'grey literature', often derived from diverse studies (environmental, ecological or consultative reports) which include polychaete species records and taxonomic keys but which fail to become more widely available, despite contributing to the overall understanding of the diversity and zoogeography of this taxonomically difficult group.

Polychaetes comprise the greatest percentage of the community of soft substrata and are the most important taxon in these communities (e.g. Knox, 1977; Guerreiro et al., 1996). Yet, despite this importance, much taxonomic research is required, especially on
tropical species, before a complete appraisal of the diversity and biogeography of this taxon is achieved. Major revisions to families are long and laborious processes, but they must be undertaken for those families where needed. Furthermore, revisions of families must be based on material, not descriptions, since interpretation of descriptions frequently is dependent on poorly understood and used terminology, which has obscured species differentiation in the past (see Fauchald, 1977).

**Crustacea**

Species richness among the vast phylum Crustacea varies considerably with taxonomic class, as does the level of knowledge on each taxonomic group. In general, the smaller the size of the organisms, the less known is the taxon. For example, ostracods, tanaids, mysids, cumaceans and amphipods, most usually less than a centimetre in length, are very poorly known from the western Indian Ocean region as well as other tropical areas. Decapod groups such as those including the lobsters, shrimps and crabs by comparison are well known. The meagre information on the former groups in part reflects the absence of specialists, while the former taxa, which include many species of commercial interest, have attracted greater attention of taxonomists.

In general the Crustacea are widely distributed, with the bulk of species from the western Indian Ocean occurring at sites across the Pacific Ocean. This distribution is mainly attributable to the extended larval life of many Crustacea. There is thus very little evidence for regional endemism. Among the Grapsidae and Ocyopodidae from Tanzania and Madagascar, Hartnoll (1975) found a very limited level of endemism, with the majority of species occurring in both these sites and in the Malay-Indonesia area. Myers (1997) reasons that crustaceans with planktonic larvae have the greatest potential for extending their distribution. Furthermore, for the development of endemism, colonisation of new areas must be followed by a cessation of gene flow from donor regions to the new area for a long enough period to allow genetic isolation mechanisms to act. If this is the case, and larvae of the widespread species are constantly being supplied, the lack of endemism among crabs and other crustaceans with long planktonic life periods (e.g. lobsters of the genus *Panulirus*) can be partly explained.

Among caridean shrimps Bruce (1984) reported that of the 133 carideans found on the Seychelles, 16.5% were endemic to the western Indian Ocean and the remainder extended to the Malay-Indonesia area and beyond. However, Bruce (1998) later concluded that for the many coral-associated pontoniine shrimp species (which generally account for about half of the caridean fauna) the distributions are still not well known, due largely to the haphazard nature of collecting activities. For crustaceans with short larval stages, or none at all, the picture does appear to be somewhat different.

Of the Amphipoda (which brood their young), Madagascar supports 9% endemism of genera and 45% endemism among species (Ledoer, 1982, 1986). The great species diversity among the amphipods, and other peracaridans (isopods, tanaids, cumaceans and mysids), which results from egg brooding as opposed to larval dispersal, results in large proportions of these taxa including as yet undescribed species.
Mollusca

The preliminary mollusc species checklist for the region provided by Richmond (1999) includes a minimum of 2550 species of gastropod prosobranchs from 75 families, 39 species of polyplacophorans representing 6 families and a minimum of 667 species of bivalves from 49 families. Among the gastropod prosobranchs, the most species-rich families were the Mitridae with 210 species, Conidae (198), Muricidae (187), Turridae (180) and Cypraeidae (97). Of the remainder, several families included in the checklist are considered little known. These tend to include members which are smaller than 10 mm, from deep water or from cryptic or parasitic habitats (e.g. living in sponges, or on echinoderms). The chitons, though few in number, are relatively well known, thus the diversity reported can be considered to be a reliable measure of the true diversity of this group.

The bivalve fauna has been less documented for the western Indian Ocean than the prosobranch fauna. Few detailed studies of bivalves exist and the checklist was compiled from only 30 sources compared to 72 used in preparing the prosobranch checklist. The most diverse families are the Veneridae with 101 species, Tellinidae (68) and Pectinidae (51).

The prosobranch molluscs described above have been studied intensively by numerous malacologists around the world over the last one hundred years. These studies, often in isolation, have resulted in confusing synonyms that plague a large proportion of the fauna, preventing regional comparisons from being made. Of those families that have been reviewed recently (e.g. Conidae, Cypraeidae, Cassidae, Littorinidae and Strombidae) the trend seems to be that most genera are widespread and smallscale endemism is apparent in areas of the Indo-Pacific.

For the western Indian Ocean, endemism varies between groups from 0–15%, some of which may be explained by larval dispersability and habitat. For example, Vermeij (1972, 1973a,b) found that many snails inhabiting the high intertidal zone have strikingly narrow geographical ranges compared to species lower down the shore. Citing examples from Kenya, Vermeij described how 6 of 13 species (46%) of snails found high on the limestone cliffs were restricted to the Indian Ocean while from the lower shore only one of 14 species was endemic to the Indian Ocean. A similar pattern was found in the northern Red Sea. Studies from Barbados, Hawaii and the Red Sea show that upper-shore gastropods exhibit a reduced planktonic phase or none at all and that the dispersal stage limits the spread of the species as a whole (Lewis, 1960; Kay, 1967). Vermeij (1978) also noted that the inshore gastropods adapted to harsh, sand-scoured shores in Brazil demonstrate more endemism than those of the less harsh lower shore or occurring under boulders. Whether a similar pattern exists in the western Indian Ocean remains to be determined.

Echinodermata

Echinoderm research in the Indo-Pacific region has benefited enormously from the comprehensive and invaluable monograph of Clark and Rowe (1971). Nevertheless, in a study of the fauna of the Seychelles, Clark (1984) found only 151 species and concluded
that "...it is clear that the echinoderm fauna of the western Indian Ocean is relatively limited in comparison to the rich fauna of the Malaysian/Indonesian area, having few characteristic species and only a small proportion of the widespread ones". Richmond (1999) demonstrated that this is no longer the case, reporting a total of 419 echinoderm species for the region, with over 100 species (25%) considered to be endemic and a large proportion of the fauna (53%) comprised of widespread Indo-Pacific species. Explanations for these observed patterns are associated with larval dispersal (across the Indian Ocean and along the northern shores), dispersal of adults on floating material and the presence of a widely distributed ancient fauna.

Since the publication of the monograph by Clark and Rowe (1971) to date, 156 new species records for the region—equivalent to an increase of 59%—have been documented. The increase in species diversity is not wholly surprising. A single study of Aldabra echinoderms (Sloan et al., 1979), only 10 years after the monograph data ceased to be collected, added 30 species to the records of the Seychelles. The increase of the known species over this period is also not exceptional to the western Indian Ocean. Pawson (1995) in a recent update of the echinoderm fauna of the Pacific islands found that the records of species diversity of that province had increased by 38%, largely attributed to the detailed work around the New Caledonia reefs by Guille et al. (1986). An increase in the known total number of species from southern China waters from 298 (Clark and Rowe, 1971) to 457 is shown by Liao and Clark (1995), resulting in an increase of 53%. Price (1982) demonstrated an increase in known species diversity for the Red Sea from the figure of 183 (Clark and Rowe, 1971) to 231, an increase of 26%.

In examining the overall diversity, direct comparisons of the western Indian Ocean fauna can be made with that of other provinces within or adjacent to the Indo-Pacific from where recent studies have been conducted. Table 2 shows that, as stated by Clark (1984), and many others, the Malay–Indonesia province is the richest as regards echinoderm diversity, though the western Indian Ocean fauna is by no means poor by comparison. Taxonomic uncertainties do exist with respect to the western Indian Ocean fauna, and further research is required to establish the true identity of a small component of the fauna.

Bryozoa
These small, often incrusting, colonial organisms have received scant attention from taxonomists in most parts of the world. The western Indian Ocean is no exception as Hayward and Yonow (1997) describe, despite these authors estimating that possibly 500 species occur in this region.

Asciidiacea
Ascidians, like bryozoans, contribute greatly to the marine diversity of shallow and deep seas, and similarly have been ignored by taxonomists. The widespread lack of ascidian taxonomic expertise is in part due to the difficulties associated with identification of a
Table 2. Echinoderm diversity for provinces within and adjacent to the Indo-Pacific

<table>
<thead>
<tr>
<th>Families</th>
<th>WIO$^6$</th>
<th>Southern Africa$^1$</th>
<th>Arabian Sea$^2$</th>
<th>Red Sea$^2$</th>
<th>Malay-Indonesia$^3$</th>
<th>Northern Australia$^3$</th>
<th>China Japan$^4$</th>
<th>Pacific islands$^5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crinoidea</td>
<td>19</td>
<td>17</td>
<td>15</td>
<td>18</td>
<td>91</td>
<td>46</td>
<td>62</td>
<td>40</td>
</tr>
<tr>
<td>Asteroidea</td>
<td>58</td>
<td>99</td>
<td>51</td>
<td>29</td>
<td>108</td>
<td>102</td>
<td>78</td>
<td>105</td>
</tr>
<tr>
<td>Ophiuroidea</td>
<td>132</td>
<td>124</td>
<td>77</td>
<td>49</td>
<td>157</td>
<td>128</td>
<td>131</td>
<td>103</td>
</tr>
<tr>
<td>Echinoidea</td>
<td>62</td>
<td>59</td>
<td>45</td>
<td>48</td>
<td>89</td>
<td>70</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Holothuroidea</td>
<td>148</td>
<td>108</td>
<td>45</td>
<td>80</td>
<td>161</td>
<td>114</td>
<td>101</td>
<td>114</td>
</tr>
<tr>
<td>Total</td>
<td>419</td>
<td>407</td>
<td>233</td>
<td>224</td>
<td>606</td>
<td>460</td>
<td>457</td>
<td>452</td>
</tr>
</tbody>
</table>

Sources: $^1$Thandar (1989); $^2$Price (1982); $^3$Clark & Rowe (1971); $^4$Liao & Clark (1995); $^5$Pawson (1995); $^6$Richmond (1999).

A large proportion of these organisms, and the absence of funding generally for a group considered, in the past, to be of little economic importance. Monniot (pers. commun.) noted that any estimates for this group are highly unreliable, as they are so little known from the western Indian Ocean.

**Pisces**

Fish, together with molluscs, are perhaps the best known marine taxa from the western Indian Ocean. Several comprehensive texts are dedicated to the taxonomy of this large and economically important group and the diversity present in the western Indian Ocean is well known. Most species are widely distributed throughout the Indo-Pacific, though the precise explanation for this pattern is not clear. Larval dispersal for example cannot account for the distribution of all species since the relationship between larval longevity is not supported by the observed distribution of adults (see Wellington and Victor, 1989; Thresher et al., 1989). For Hawaiian shorefish Randall (1995) reported 24.3% endemism and related the presence of some of the fauna to the geological history of the Pacific Plate rather than larval distribution.

Analysis of the reef fishes of the entire Indo-Pacific confirms that the Indo-Australian Archipelago is a 'center' of diversity with over 3000 species of shorefish (Carcasson, 1977; Lieske and Myers, 1994). They also found that within the western Indian Ocean, the Mascarene islands are characterised by a significant endemic element, and that species diversity in this region, although high, is less than that of the central Indo-Pacific. For example, Allen (1991) found that of the 268 known damselfish species (family Pomacentridae), 24 are endemic to the western Indian Ocean.

**BIOGEOGRAPHY AND ENDEMISM**

Richmond's (1997) summary found that of the 1500 fully aquatic taxa for which reliable distribution information could be ascertained, the majority (70%) occur at sites extending to the western Pacific Ocean (half of which occur beyond and into the central Pacific). Of
the total, 15% were found to be endemic to the western Indian Ocean. These figures indicate only a broad pattern since they represent only the most common and typical coastal species. Notwithstanding, this serves as a general estimate which compares with the findings from the few well studied taxa described above. Gosliner and Draheim (1996) took a similar approach. In considering levels of endemism of Hawaiian opisthobranchs, they regard the figure of 43% (of all species known to occur only in Hawaiian waters) to be less reliable than the estimate of 4% endemism derived from figures only for the larger, more conspicuous and better known species. The latter they regard as less likely to be overlooked.

Three phenomena affect almost all aspects of biogeography: sampling, dispersal and evolution (Williamson, 1988). With regard to the origins and geographical distribution of the western Indian Ocean marine taxa, discrepancies arising from regionally unequal sampling indicates that any figures and observed patterns should be interpreted with caution (Veron, 1995; Gosliner et al., 1996; Paulay, 1997). The resulting paucity of reliable distribution records for many invertebrate taxa continues to be an intrinsic problem for the study of biodiversity (Myers, 1996) and is still applicable to most parts of the tropics. For many taxa, discussions on biogeography and origin cannot be undertaken since so little is known. For example, an analysis of the Indo-Pacific opisthobranch gastropod biogeography by Gosliner and Draheim (1996) entitled in part "... how do we know what we don't know?" points out the lack of baseline data even from localities that were believed to be well known (Hawaii) from which they claim the known diversity of opisthobranchs has increased by 75% in the last 3 years alone. Similarly, Sheppard (1998) recommends that with respect to Indian Ocean corals, the taxonomy still requires considerable revision despite the substantial improvements achieved recently, a condition which may also apply to many other groups in the Indian Ocean.

An overall estimate for regional endemism of about 15% (as noted above) may prove realistic although further taxonomic and biogeographical work is required, not only within this region but also throughout the Indo-Pacific. A well-known Coelocanth (Latimeria chalumnae Smith, 1938) was considered endemic to the southwestern Indian Ocean (Smith and Heemstra, 1995) until the discovery in July 1998 of this species from 100–150m depth off north Sulawesi (Indonesia), 10,000km from its known population around the Comoros Islands (see Erdmann et al., 1998). This discovery has major biogeographical and conservation implications for the fish, but also serves as a clear reminder to biogeographers of the continued need to give observed biogeographic patterns only as much confidence as a knowledge of the sampling efforts invested in providing the data on which patterns are based.
SPECIES RICHNESS AND AREA SIZE

The subject of whether the central Indo-Pacific, encompassing the coastal waters of the Philippines, Indonesia and Papua New Guinea, should be considered the ‘center and focus’ from which other sub-regions of the Indo-Pacific have recruited species, as Ekman (1953) suggested, has been examined by many (e.g. Ladd, 1960; Taylor, 1971; Briggs, 1974; Abele, 1982; Kay, 1984; Rowe, 1985; Donaldson, 1985). A summary of these and other studies suggests that this region, undoubtedly the richest in species diversity, has achieved this condition by maintaining a rich biodiversity derived from a widespread, warm, Tethyan Sea biota which was present up to the Late Eocene, about 45 million years ago (Vermeij, 1978). Speciation in some taxa would certainly have occurred while additional taxa from neighbouring areas were also accumulated. An example of the former resulted from the drying of the Sunda Shelf in Indonesia during the Pleistocene period which effectively separated the Pacific from the Indian Ocean. This event promoted speciation in a number of mangrove-associated taxa which after the post-glacial sea-level rise contributed to enhance the diversity of these groups (Vermeij, 1978).

All other regions within the Indo-Pacific support less diversity. Examples of these less diverse areas include the central Pacific islands, the Red Sea and the western Indian Ocean, all of which demonstrate high levels of endemism. The development of marine biodiversity in these sub-provinces of the Indo-Pacific probably began with some of the widespread Tethyan biota. Subsequently, part of this taxa would have been lost during sea-level and other tectonic changes, while over time, additional species from the Malay-Indonesian region (which may have either existed since Tethyan times or developed subsequently) may have accumulated. Finally, these sub-provinces also developed their own unique biota through speciation.

The central Indo-Pacific region is characterised by thousands of islands of varying sizes and geology, a wide continental shelf and a rich diversity of coastal habitats. Geographical areas (provinces) defined in any study differ greatly in size, habitat diversity and extent, thus direct comparisons of diversity cannot be made. Abele (1982) demonstrated that the overall area of the four large tropical regions he examined (eastern Atlantic, western Atlantic, eastern Pacific and Indo-West Pacific) accounted for 98% of the variation in the number of crustacean species from these regions. He also found that shrimp species number in the West Indies was strongly related to the perimeter length of the islands.

While estimates of the coastal areas for the Indo-Pacific provinces considered for echinoderms in Table 2 may be difficult to obtain, coastline length data are given in Table 3, together with echinoderm species numbers for each of the provinces. Coastline length measurements for whole countries were mainly taken from Couper's (1989) Times Atlas of the Oceans, with portions of country coastlines forming part of provinces derived from estimates. Though these coastline length measurements may include an error of unknown dimension (but likely to be small, and equal to all data sets), they provide an opportunity to examine the presence of a relationship with echinoderm species...
Table 3. Echinoderm species diversity and coastline length (km) for provinces within the Indo-Pacific

<table>
<thead>
<tr>
<th>Province codes</th>
<th>WIO</th>
<th>E. Africa/ Madag.</th>
<th>WIO islands</th>
<th>Arabian Sea</th>
<th>Red Sea</th>
<th>Northern Australia</th>
<th>China</th>
<th>Malay-Indonesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species no.</td>
<td>419</td>
<td>373</td>
<td>215</td>
<td>191</td>
<td>224</td>
<td>460</td>
<td>457</td>
<td>606</td>
</tr>
<tr>
<td>Coastal length</td>
<td>11,612</td>
<td>10,754</td>
<td>858</td>
<td>6058</td>
<td>5730</td>
<td>12,800</td>
<td>18,844</td>
<td>89,654</td>
</tr>
</tbody>
</table>

Species number from Table 2; province coastline lengths based on Couper (1989) (see text); province codes relate to Figure 2.

![Graph showing the relationship between coastline length (km) and number of species]

Figure 2. Echinoderm species number plotted against coastline length of Indo-Pacific provinces (see Table 3 for province codes)

number. A plot of these data against the number of species is shown in Figure 2. The relationship between coastline length and echinoderm species number is given by the formula \( y = 97.062 \ln(x) - 523.21 \), with \( R^2 = 0.741 \), indicating that species number is a strong function of coastline length.

Explanations for the relationship shown in Figure 2 between coastline length and species diversity are certain to include the influence that coastline length has on habitat heterogeneity which is known to strongly affect species diversity (Ricklefs, 1979; Williamson, 1988) and must itself be a function of length of coastline. However, certain coastlines in the Indian Ocean exist which are likely to fail to conform to the above. The western shores of India for example, though lengthy, are predominantly of fine sediments and prone to high freshwater influences, not suited to echinoderms.

To test the reliability of the relationship shown in Figure 2 more data are needed, especially within the coastline length ranges of 20,000–80,000km for which species diversity must also be ascertained. Although it cannot be concluded from the relationship derived from this brief analysis that echinoderm species diversity is simply a function of
the length of coastline sampled, the findings do indicate that further examination of this coastal perimeter effect may reveal interesting results.

**REASONS FOR HIGH BIODIVERSITY**

Differences between the biodiversity of the western Indian Ocean islands (Mascarenes and Seychelles) and that of the East Africa mainland and Madagascar are apparent. Particularly noticeable are the differences in the diversity of molluscs (and of echinoderms) and bivalves. From an analysis of the molluscan fauna of tropical continental and oceanic islands Kohn (1971) found a ratio of prosobranchs to bivalves of 2.2:1 for continental islands and 4.8:1 for oceanic islands, providing further evidence that in continental environments, a greater diversity and contribution of bivalves is manifest. Bivalves probably evolved in shallow, coastal, continental waters rich in suspended material (Salvat, 1967; Taylor, 1971) and their adaptive radiation into coral reef habitats has only been achieved by a few families involving relatively fewer genera (Morton, 1983). The echinoderm species diversity study by Richmond (1999) found that eastern Africa (including Madagascar) supported 373 species (with 81 endemics), while from the western Indian Ocean islands only 215 species (with 15 endemics) have to date been reported.

These differences are not surprising given the differences in the physical properties (size, geological history and location). Differences in habitat diversity and extent are also great. For example, the islands lack any significant development of mangrove forests and estuarine conditions common along parts of the mainland and Madagascar shores. The isolation of the islands (e.g. Mauritius and Réunion) however contributes to the overall diversity of the region by favouring speciation and endemism (see Barnes and Hughes, 1982). In addition, the presence of a mixed or boundary region off South Africa, contributes by providing an element of warm temperate taxa, thus increasing the biodiversity of the southwestern portion of the region. The remoteness of many of the smaller islands in the region from human habitation (and possible degradation as increasingly found on mainland shores) may also create reservoirs of intact communities and thus sources from which export of larvae to neighbouring degraded areas can take place.

**FUTURE RESEARCH**

The mangroves, seagrasses, macroalgae, scleractinian corals, the prosobranch molluscs and some of the bivalves, most of the decapod crustaceans, echinoderms and fish are taxonomic groups which can be considered to be reasonably well known. These account for about 75% of the total estimate of species of shallow-water taxa for the region (see Table 1). Even within these groups there remain areas under study, resolving taxonomic uncertainties and discovering new species. Among the remaining, lesser-known taxa, taxonomic and biogeographical studies will almost certainly reveal new species (or genera),

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new records and progress towards resolving systematic ambiguities. During the work in preparing the guide book, previously undescribed species of macroalgae, Porifera, Octocoralia, Cirripedia, Amphipoda, Nudibranchia, Holothuria and Asciidiacea were found and have or are being described. At present, it is likely that any detailed study on marine invertebrate taxa in the western Indian Ocean will reveal new records for the region as well as new species.

Though much of the taxa present in the waters of this region is well documented, very little about the biology of the organisms, their reproductive needs, feeding habits, interactions with other species and role in the ecology of their habitats is understood. We also know that we are losing taxa through habitat destruction, pollution and climatic events such as the most recent 1998 El Niño-induced coral bleaching. Larger animals such as the dugong and several marine turtles are locally threatened with extinction. Taxonomy should not therefore be the focus of marine research by regional scientists. The science of taxonomy requires many years of experience, access to extensive taxonomic collections, type material and specialised literature, most of which are not present in the region. Funding for taxonomic research has suffered considerably in many countries which previously contributed greatly to taxonomic knowledge (e.g. France and the United Kingdom) with the result that globally there has been a reduction in this field of biology. Funding for such research in the western Indian Ocean is not likely to develop significantly. The focus of regional marine scientists should instead reflect the region’s needs. More specifically the priorities should be to develop effective methodologies and policies to conserve the marine biodiversity which we are already aware of. Effective policies to ensure benefits from bioprospecting activities should also be initiated.

The encouragement of specialist taxonomists to visit the region and add to the knowledge and collections should nevertheless continue, thus furthering our biodiversity knowledge and updating the taxonomy of the flora and fauna. There is a need to continually revise species checklists for the region by making them widely available to specialists. A significant contribution to this process was initiated in late 1996 by the Kenya-Belgium Project which has been compiling a database for a number of taxonomic groups. Under the MASDEA - Marine Species Database for Eastern Africa project approximately 22,890 distribution records, and 10,160 taxon records are currently entered. There are additional 500 family-level records, all derived from over 230 literature references. Such a database will greatly assist in the dissemination of information and is being expanded to cover other taxa. The production of freely distributed reports is currently being undertaken by Sida (Swedish International Development Agency) for mangroves, seagrasses and corals, using CD formats. World or regional species checklists and distribution records are also now available on the Internet for some groups e.g. Indian Ocean macroalgae (University of California Berkeley) and freshwater and marine isopods of the world (Smithsonian Institution). Together, these sources will, with time, greatly assist in developing a more precise estimate of the marine biodiversity for the region.
ACKNOWLEDGEMENTS

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REFERENCES


Coral reef structure at Zanzibar Island, Tanzania

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ABSTRACT

This study examined the structure of coral reefs around Zanzibar Island (Unguja), Tanzania. The study, which was carried out from November to December 1997, gives a description of the substrate composition and topographic structure both in the more exposed northeastern part of the island as well as in the more sheltered western areas. A point-base method was used to calculate site-specific proportions of live cover, hard coral, soft coral and algae. The number of coral growth forms, substrate diversity (N) as well as the reef contour (rugosity) was also examined. Further, to measure the intrinsic structure of the reef and not just the contour, the percent branching structures was introduced as a measure of structural complexity. The 11 sites that were investigated differed in reef structure and composition of the substrata. Live cover (including all sessile organisms) ranged from 65% at N. Mnemba on the northeastern coast to 95% at Changuu in the western part of the island. Hard coral cover ranged from 2% at Kichwani to 78% at Pange. Soft corals comprised the dominant taxa in the northeastern region but were almost absent at the western sites. Algal cover was lowest at Pange (9%), west of Zanzibar town, and highest at Kendawi 4 (39%) in the northwestern part of the island, where 30% of the reef was covered with turf algae. Substrate diversity was higher in the northwestern and northeastern regions than on the western reefs, which were dominated by extensive mono-stands of branching corals. Consequently the western reefs exhibited higher percent branching corals than the northeastern and northwestern reefs. The variation in rugosity exhibited a similar but weaker pattern. The importance of considering different levels of detail (resolution) when measuring the structural complexity of reef habitats is discussed. Given the variation in wave impact and current patterns around Zanzibar Island, it is suggested that hydrodynamics is an important structuring factor on these coral reefs.

INTRODUCTION

Coral reefs line the coast of East Africa and provide an invaluable resource base for many coastal communities (Salm, 1983; Hamilton and Brakel, 1984; Muhando, 1997;
Johnstone et al., 1998). The East African reefs have been characterised as being situated in a discrete zoo-geographic sub-region (Sheppard et al., 1992; Sheppard, 1997), with a potential significance as recipients and re-distributors of remote generic material via the equatorial currents (Veron, 1995). Due to the narrow continental shelf most reefs are fringing reefs which remain close to the coast, while others surround islands and sandbanks further from land. The coral reefs of East Africa have received comparatively little research attention despite being important natural resources with a large number of people depending on them for their livelihood (Andersson and Ngazi, 1995; Dulvy et al., 1995; Andersson, 1997; Jiddawi, 1997; Khatib, 1997; Semesi et al., 1998). With the exception of some studies from selected sites (e.g. Gaudian et al., 1990; Björk et al., 1995; Dulvy et al., 1995; McClanahan, 1994; Nzali et al., 1998; McClanahan et al., 1999), there is little quantitative information on the effects of these activities.

There are a limited number of studies that have quantified the structure of Tanzania’s coral reefs (e.g. Talbot, 1965; Hamilton and Brakel, 1984; Dulvy et al., 1995; McClanahan et al., 1999). Recent studies report 150 species of corals from Zanzibar (Johnstone et al., 1998). However, a complete inventory of these reefs remains to be carried out. Meanwhile, a widespread degradation of the reefs and their associated resources has been reported (Bryceson, 1978; Ngoile, 1990; Guard and Masaiganah, 1997; Wagner, 1997; Muhando, 1997, 1998; Johnstone et al., 1998; Salm et al., 1998). One of the main threats is over-exploitation (Ngoile et al., 1988; McClanahan et al., 1999). Fishing effort in Tanzania is believed to have doubled in < 20 years (McClanahan et al., 1999), and destructive methods are commonplace (Jiddawi, 1997). In addition, sedimentation, eutrophication and pollution add chronic stress to many reefs on Zanzibar as well as the Tanzanian mainland (UNEP, 1989; Muhando, 1997). Given the paucity of knowledge of reef community structure in the area, and the environmental changes that these communities are subjected to, the present study sought to quantitatively describe a number of reefs around the coast of Zanzibar Island, Tanzania in terms of substrate composition and structural complexity. The investigation further aimed at comparing two measures of structural complexity of the reef habitat, using two levels of detail.

METHODS

Study sites
Zanzibar Island (Unguja) is the largest island of Tanzania (Figure 1). It is situated 35km from the Tanzanian mainland in the western Indian Ocean. On the eastern ocean-facing side of the island nearshore fringing reefs span the coastline. The reefs, which are exposed to strong waves and currents, are limited in extent and consist mainly of a reef flat and a reef slope (Ngoile, 1990). In the Zanzibar channel, between Zanzibar Island and the mainland, the continental shelf is wider than in the eastern area. The more protected side supports a number of small islands and sand bars fringed by coral reefs. Overall, the coastal climate, surface currents and other hydrographic conditions are
influenced by the typical conditions of the inter-tropical convergence zone (ITCZ) with a southeast (April to October) and a northeast monsoon (November to March). In comparison to the southeast monsoon, the northeast monsoon is characterised by lower wind speeds, cooler water temperatures, calmer seas and a reduced velocity (1–2 knots) of the East African Coastal Current (EACC). The southeast monsoon brings high winds, warm water temperatures and rough seas with the velocity of the EACC increasing to a speed of 4 knots (McClanahan, 1988). Surface temperatures reach a minimum of 25°C in September and rise to a maximum of 29°C in March. The coast is influenced by mixed semidiurnal tides with mean spring amplitude of 3.3m. Strong tidal currents of up to 3 knots are common, especially on the east coast of Zanzibar.

Reef structure and substrate composition was examined at 11 sites. The Kichwani site is situated on the southeastern side of Mnemba island, 2km off the northeastern coast of Zanzibar. The reef slopes steeply down to 15m from a reef flat, which is regularly exposed at low tides. It is subjected to extensive fishing, some of which is destructive to the reef (pers. observ.). The North Mnemba site is located at the western tip of the reef that surrounds the island. This reef is flat, shallow and comparatively eroded. It is subjected to prominent tidal currents. The site lies within a 200-m-wide zone around the island. It has been protected from all extractive use since 1989, due to tourist developments on the island.

Kendawi Reef on the northwestern coast of Zanzibar Island consists of two stretches of reef, both situated parallel to the northwestern coast of Zanzibar Island and separated by a 100m channel of sand. Two sites (Kendawi 1 and Kendawi 3) were located on the inner reef which was approximately 40m wide and situated 200m from the beach. Two additional sites (Kendawi 2 and Kendawi 4) were sampled on the outer reef, which is approximately 60m wide.

There are a number of islands, islets and sand banks in the vicinity of Zanzibar Town. Compared to the eastern coast, reefs in this area are more protected from waves and strong currents. All reefs associated with these islands, with the exception of Chumbe Island Coral Park, are influenced to varying degrees by fishing and other human impacts (Björk et al., 1995; Jiddawi, 1997). The Pange site is situated at the northwestern side of the Pange sand bank, 1.5km southwest of Zanzibar Town. The Bawe site is situated on the northeastern side of the reef surrounding Bawe Island, 5km west of Zanzibar Town. The Chumbe Island Coral Park (CHICOP) was established in 1992 to manage the reefs surrounding Chumbe Island, 8km south of Zanzibar Town. Fishing is strictly banned and all tourist activities are controlled by rangers operating in the park. The Chumbe site is located along a fringing reef on the western side of the island. Changuu Island, situated 2km northwest of Zanzibar Town, is a popular snorkel and dive site for tourists. Two sites (Changuu 1 and Changuu 2) were sampled; Changuu 1 on the northeastern side of the reef and Changuu 2 on the western side.

Field methods
In order to characterise bottom composition and structure we used the point-base method (Wiens and Rotenberry, 1981), modified to the coral reef environment. The
technique provides an estimate of the percentage cover of the various substrate categories. A stretched 20m tape was laid out perpendicular to the reef front. The depth of the transect varied between 3 and 8m. At 1m intervals, and perpendicular to the 20m transect line, a 2m rope was positioned, stretching towards alternating sides of the transect line. At five randomly assigned points along the 2m transect line, the character of the substrata was recorded. Hence, there were 105 sampling points per 20m transect. The categories were chosen to reflect both taxonomic and structural identity. As a measure of large-scale structural complexity, a line following the bottom contour was laid out along every other of the 2m transects. The total distance covered by this line was then divided by 2m (the horizontal distance covered by the transect line), producing an index of rugosity (R) (Risk, 1972). All procedures were replicated five times with at least 45m inter- replicate distances at all 11 sites.

**Data analyses**

Percentage cover of each substratum category was calculated as the percentage of the 105 points on each transect. Percentage live cover was calculated by adding all points that were occupied by living benthos. Substrate diversity (N) was calculated as the diversity of cover of substratum categories using the formula:

\[
N = \exp(-\sum p_i \ln p_i)
\]  

where \( p_i \) is the proportional coverage of the ith substratum category (Green, 1996). Rugosity was described by the index R, calculated by comparing bottom contour distance with straight line distance at half of the 2m transects perpendicular to the main transect (Risk, 1972).

\[
R = \frac{\sum (\text{bottom contour distance} / \text{2})}{10}
\]  

All percent living and dead branching substrata were added to generate a measure of structural complexity (Table 1). Furthermore, the mean number of hard coral growth forms (i.e. branching, digitate, encrusting, foliaceous, free-living, massive and plate coral) was recorded for each site.

The substrate composition of the 11 sites was furthermore classified by hierarchical agglomerative clustering using complete linkage.

**RESULTS**

Coral reefs in the coastal waters of Zanzibar varied in substrate composition and structure (Table 1, Figure 2). The Kruskal-Wallis test identified significant differences in live cover, hard coral, soft coral, algae, number of coral growth forms, substrate diversity, rugosity and branching structures (Table 2). Cluster analysis of the substrate data (Figure 3) indicate a major division of the two northeastern sites, N. Mnemba and Kichwani from the other 9 sites on Zanzibar. Kendawi 1–4 on the northwestern coast and Bawe, Changuu
Table 1. Average and standard deviation percent cover of each of the pre-defined categories at all 11 sites

<table>
<thead>
<tr>
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<th>Bawe Av</th>
<th>Chumbe Av</th>
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<td>Turf algae on massive</td>
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† = substrate categories used to calculate the percent branching structures.
Figure 2. Mean (SE) of the recorded substrate variables at 11 sites in Zanzibar. Northeastern region: Kich, Kichwani; N. Mn, North Mnemba; Northwestern region: Ken 1–4, Kendawi 1–4; Western region: Chum, Chumbe; Cha 1–2, Changuu 1–2
Table 2. The variability in abundance of major substrate groups on 11 reef sites around Zanzibar as measured by the Kruskal-Wallis test, in which the significance level (p) of the test-statistic (T) is based on the Chi-squared distribution with 10 degrees of freedom

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<td>Number of growth forms</td>
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<tr>
<td>Rugosity</td>
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<tr>
<td>Fine-scale structural complexity (FHC)</td>
<td>39.97</td>
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** 0.001 < p < 0.01, *** p < 0.001.

![Diagram showing hierarchical agglomerative clustering (complete linkage) of substrate variables at 11 Zanzibar reef sites.]

Figure 3. Hierarchical agglomerative clustering (complete linkage) of substrate variables at 11 Zanzibar reef sites

1–2 on the western coast outside Zanzibar town form two sub-clusters, which nevertheless exhibit certain similarities. Two of the western reefs, Pange and Chumbe, are distinctly separated from all other sites.

The northeastern reefs (N. Mnemba and Kichwani) were comparatively poor in terms of coral cover, coral growth forms and structural complexity, but rich in terms of soft coral and algae. Live cover at Kichwani was comparative to that of the Kendawi sites, and low compared to the western sites. North Mnemba exhibited the lowest live cover (65%) of all sites.
On the northwestern coast, the Kendawi reef sites were relatively homogeneous in terms of live cover, coral cover, coral growth forms, rugosity and branching structures, all of which were higher than at the northeastern sites. The hard coral community was dominated by large monostands of *Galaxea fascicularis* and hence these reefs were distinct from the reefs in the vicinity of Zanzibar town, where branching and digitate corals comprised the predominant growth forms. Soft corals comprised 9–23% of the substrate at Kendawi, which was less than at Kichwani and N. Mnemba in the northeast but more than at the western sites, where soft corals were virtually absent. All northwestern sites exhibited higher substrate diversity than the sites close to Zanzibar town and Kendawi 3 exhibited the highest substrate diversity of all.

The western reefs all exhibited high live cover (92–95%) but were in other aspects quite heterogeneous. Bawe, Changuu 1 and Changuu 2, which were aggregated in the cluster analysis, showed similarities with the northwestern Kendawi reef sites. The former sites exhibited moderate coral cover, coral growth forms, branching structures and diversity. At Bawe algae cover was almost as high as at Kendawi 4, where the highest algal abundance was recorded.

Chumbe and Pange reefs were dominated by large monostands of branching corals (*Porites* and *Montipora*). The highest hard coral cover was consequently recorded at Pange sandbank (78%) and at Chumbe (75%) and so was the highest percent branching structures (58 and 70% respectively). In contrast, algal cover was poorest at Pange and Chumbe and soft corals were almost absent. This distinct cluster exhibited moderate rugosity and diversity was the lowest among all sites.

**DISCUSSION**

Coral reefs in the coastal waters of Zanzibar differed in substrate composition and structure. Among the examined sites three distinct aggregations were identified in the cluster analysis. The reefs in the northeast were characterised by poor coral cover, high soft coral cover, low structural complexity and comparatively high substrate diversity (N). The northwestern reefs were relatively homogeneous, exhibiting medium coral cover, soft coral cover and structural complexity. The prevalence of rubble on Kendawi 1–4 as well as on N. Mnemba suggested that live coral cover was higher in the past. The Kendawi Reef was unique in terms of composition with some resemblance to the Zanzibar town reefs of Bawe, Changuu 1 and Changuu 2. These three reefs did, however, exhibit higher live cover, coral cover, structural complexity and lower substrate diversity.

Chumbe and Pange reefs were most distinctive due to the very rich coral community, which was dominated by large monostands of branching corals. It is noticeable that although substrate diversity was the lowest recorded in this study, Chumbe and Pange have been reported to have the highest numbers of coral genera in Zanzibar (Gaudian et al., 1990). Generally, at the examined sites, corals were scarce where diversity was high. Consequently the value obtained for N reflected a high diversity of non-scleractinian
organisms. For example, Kendawi reef sites harboured comparatively higher proportions of ascidians, corallimorpharians, sponges, hydrozoans and *Tubipora*.

The results presented in this study demonstrated among-site differences promoted by various biotic and abiotic factors. Prevailing hydrodynamic regimes and physical disturbance are likely to influence bottom composition (e.g. Connell et al., 1997). Hydrodynamic effects are determined by the degree of embayment and the width of the continental shelf among other factors. Hydrodynamic conditions clearly differed between the eastern and western reefs and these conditions are likely to be reflected in substrate composition. For example, soft corals, the predominant substrate category at the more exposed Kichwani, are known to thrive in environments subjected to strong water movement (Fabricius, 1997) while many species of hard corals are sensitive to wave impact and forceful currents (Roberts, 1974; Dollar, 1982). Encrusting coralline algae are also common where wave energy is high (Björk et al., 1995) and indeed Kichwani supported the highest abundances. In addition, biotic processes, such as recruitment, competition and predation are also important factors in structuring the benthic community. Finally, human activities, whether passive (e.g. sedimentation and eutrophication) or active (e.g. fishing and tourism) influence reef structure and composition at Zanzibar (e.g. Muhando, 1997; Jiddawi, 1997; Wagner, 1997; McClanahan et al., 1999).

Structural complexity was described at two different levels of detail: rugosity at lower resolution, and percent branching structure at higher resolution. The two measurements generally rendered similar results; low rugosity and proportion of branching structure at the northeastern sites, moderate at Kendawi 1–4 and somewhat higher in the Zanzibar channel. However, rugosity was more homogenous among sites than the percent branching structures. For example, reefs in the Zanzibar channel differ little in rugosity, but a great deal in terms of branching structures. Clearly two measures of structural complexity gives a more comprehensive description of the reef habitat.

ACKNOWLEDGEMENTS

We thank Julius Francis and Christopher Muhando at the Institute of Marine Science, University of Dar es Salaam, Tanzania and Sara Svensson, Dept of Zoology, Stockholm University, for their support. This study was financed by the marine zoology component of the Sida-SAREC Bilateral Marine Science Programme between Sweden and Tanzania as well as the Regional Sida-SAREC Marine Science Programme of East Africa for coral reef research. Valuable comments on the manuscript were given by Matt Richmond.

REFERENCES


The reproductive biology of *Thalamita crenata* (Latreille) at Gazi Bay in Kenya

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ABSTRACT

The brachyuran crab *Thalamita crenata* (Latreille) occurring intertidally along the Kenyan coast was sampled at Gazi over a period of 12 months. The crabs were collected using scoopnets over a distance covering two kilometres along the bay. The carapace was opened up and the state of the ovaries examined during the entire study period. The developmental stages of embryos in females which had extruded their embryos were identified. The minimum size at sexual maturity was related to the state of ovaries. The fecundity of the crabs was obtained by counting the number, weighing the embryo mass and estimating their sizes. Regression analysis was used to estimate the linear relationship between fecundity and carapace width, embryo mass weight and embryo size respectively. A positive relationship was found between fecundity and carapace width, showing that fecundity increases with carapace width (t=9.908; df=205; p<0.001) and between fecundity and embryo mass weight, showing that fecundity increases with embryo mass weight (t=9.55; df=205; p<0.001) while no significant relationship was found between fecundity and embryo size (t=1.04; df=205; p>0.05).

INTRODUCTION

The presence of coral reefs and extensive mangrove areas along the Kenyan coast supports a marine fishery carried out by artisanal fishermen, who fish for finfish and crustaceans, especially crabs, prawn and lobsters. The edible portunid crabs found along the Kenyan coast include *Scylla serrata* (Forsskal), *Thalamita crenata* (Latreille) and *Portunus pelagicus* (Linnaeus). *Scylla serrata* is the largest of the three crabs and is the most preferred for consumption (Provenzano, 1985). In the Indo-Pacific regions, a lot of research work has been carried out on portunid crabs, especially *S. serrata* which occurs in large numbers and also forms part of the crustacean fishery in the region (Alverson and Patterson, 1974). Nearly all ecological aspects have been studied on this crab while the other edible crabs *Portunus pelagicus* and *Thalamita crenata* have received less attention because of their smaller sizes.
This research aims at establishing the reproductive habits of *T. crenata* because of its importance as a source of dietary protein for local communities.

**MATERIALS AND METHODS**

**Study area**

Gazi (4° 20' S and 39° 30' E) is located on Maftaha Bay, 45km from Mombasa, Kenya (Figure 1). It is a mangrove creek with a small permanent river, Kidogoweni River. The creek has a small lagoon which maintains water even at low tides. It is considered undisturbed because no industrial wastes or sewage effluents are discharged into the creek. The creek supports a small artisanal fishery which includes finfishes and prawn catches during the long rainy seasons. *Thalamita crenata* is abundant in the sandy pools and mud edge of the creek.

This study commenced in April 1990 and ended in March 1991. The crabs were caught using a scoopsnet. Sampling was conducted during low tides every day for a week each month. The distance covered during the sampling process was approximately 2 kilometres. All crabs obtained live were taken to the laboratory and preserved in a deep freezer. For each crab, carapace width (mm), body weight (to the nearest 0.1g) and sex were recorded. The number of oigerous (with extruded ovaries) female crabs was recorded and for the non-oigerous crabs, their carapace was opened up for observation of the maturity stages of the ovaries. For oigerous female crabs, the weight of embryo mass together with pleopods, developmental stages of crab embryos, embryo size (using an ocular micrometer) and maturity stages of ovary was recorded. The whole embryo mass together with pleopods was preserved in Gilson’s fluid (Bagenal and Braum, 1978). A gravimetric sub-sampling method was used to count the embryos in the entire embryo mass.

**ANALYSIS OF SAMPLES**

**Ovarian maturity stages**

The maturity stages of crab ovaries were grouped into four main stages following the procedure adopted by Pillay and Ono (1978). Observations were made under a standard binocular microscope. Ovary development was arbitrarily distinguished by the size and colour of the ovary as follows:

- **Stage 0** - Virgin/resting. Ovary very thin (<2mm) and transparent (colourless). No initiation of gametogenesis.
- **Stage 1** - Developing. Ovary is approximately 2mm thick but still thin and creamy-white in colour.
- **Stage 2** - Well developed ovary, approximately 5mm thick, broad, yellow and contains medium-sized oocytes.
- **Stage 3** - Ripe. Ovary is dark brown and practically fills the body cavity, pressing against the hepato-pancreas and the stomach. The ovary is highly lobulated and has large oocytes. After this stage the eggs are extruded onto the pleopods.
Figure 1. Sampling site of *Thalamita crenata* in coastal Kenya

**Developmental stages of crabs embryos**

This was determined following the procedure adopted by Boolootian et al. (1959) using a standard dissecting microscope. The following are the descriptions given for embryonic development.

Stage 1 - No segmentation observable, entire egg is yellow.
Stage 2 - Cleavage has taken place, i.e. the egg has several small sections.
Stage 3 - The developing embryo has two regions, a very small yolk-free (transparent) region and a larger yolky region.
Stage 4 - Distinction into two almost yolk-free and yolk-containing parts is visible.
Stage 5 - Eye pigment of the embryo visible.
Stage 6 - Light pigment bands of embryo visible.
Stage 7 - Larva strongly pigmented but still has much yolk.
Stage 8 - Yolk reduced to two small separate patches.
Stage 9 - Zoea larvae recognisable.
Stage 10 - Swimming zoea larvae emerge.

Size at first maturity
This was ascertained by noting the carapace width at which 50% of crabs were carrying embryos on their pleopods. The samples for the whole year was pooled.

Fecundity
For each ovigerous female crab, the following were recorded:
(a) Carapace width (in millimetres).
(b) Embryo mass weight, obtained by weighing embryos with pleopods, then removing the pleopods manually, measuring their weight and subtracting this from the weight of the embryo mass together with pleopods.
(c) Embryo size, obtained by measuring the diameter of 10 embryos in each of the three sub-samples using an ocular micrometer. An average size was then converted to millimetres with the help of a stage micrometer.

Three sub-samples were taken manually from each preserved embryo mass and weighed. Water was added to the Bogorov counting chamber and the embryos were spread out manually using a fine dissecting needle. Each sub-sample was counted three times and from these, the average weights and numbers were obtained. The total number of embryos was then estimated for the whole mass. The relationship of fecundity (F) to carapace width, embryo mass weight and embryo size was determined using formula of Bagenal and Braun (1978) as follows:

\[ F = a x^b \]  

Regression analysis was used to estimate the linear relationship between fecundity and carapace width, embryo mass weight and embryo size.

RESULTS

Ovarian maturity stages
Crab ovaries increase in size and undergo colour change during development, and all the four stages expected were observed in *T. crenata*. Figure 2 shows that the percentage of crabs with ovaries in stage 0 of development were few. During the months of April, June, August, November and December, no crabs had 0-stage ovaries. The percentage of crabs with ovaries in stage 1 was higher than the total percentage of crabs with ovaries in
stage 0. Only June had no female crab in that stage of development. The percentage of crabs with ovaries in stage 2 of development was high in each month throughout the sampling period except in April. There was a grey mass which was thought to be the fatty body over the bright yellow ovary (stage 2). The percentage of crabs with ovaries in stage 3 tended to be low throughout the sampling period except in June and March. Crabs in this maturity stage had the grey mass over the ovary.

Figure 2. Percentage frequency of ovarian maturity stages of female *Thalamita crenata* at Gazi Bay in Kenya

**Developmental stages of crab embryos**

As the embryos of crabs develop, they undergo marked colour changes from yellow when extruded to almost black when the zoea emerge. These embryos are attached to the pleopods and are brooded externally. Figure 3 indicates that though no ovigerous crab was obtained in April, in May the low percentage of ovigerous crabs obtained had embryos in early stages of development. By contrast, in July, most of the embryos were in stage 9 of development, indicating imminent spawning. August and September samples showed the majority of ovigerous crabs with embryos between stages 5–9. In October the ovigerous crabs obtained had their embryo stages 2 to 5, while in November embryos were mostly in stage 4 of development. December and January crabs had a considerable proportion of stage 9 embryos indicating a second spawning season in the breeding cycle. In February, ovigerous crabs had embryos in nearly all stages.
Figure 3. *Thalamita crenata* developmental stage of embryos (x = no. of non-ovigerous crabs). Size at first maturity.
Size at first maturity
The smallest ovigerous crab had a carapace width of 28.9 mm, but the ascertained size at first maturity ranged between 40.5–45.5 mm carapace width when 50% of the females collected were ovigerous. During this study a crab with carapace width of 16.75 mm had its ovary in stage 1 of development. This shows that these crabs may start maturity at a much smaller carapace width.

Fecundity
A total of 207 crabs were observed for fecundity studies. The carapace width ranged from 25.44–70.44 mm. The embryo mass weight ranged from 0.11 to 5.6 g, the embryo size ranged from 0.3 to 0.4 mm in diameter while fecundity ranged from 1521 to 209,450 embryos.

(a) Relationship between fecundity and carapace width
The highest fecundity recorded for T. crenata in this study was 207,710 embryos in a crab of 60.4 mm carapace width. A crab with carapace width of 28.9 mm held 13,650 embryos. The mean carapace width was 47 mm and mean fecundity of 74,320 embryos. The regression line fitted for fecundity on carapace width (Figure 4) was:

\[ \log_{10} F = 0.5 \times 2.4 \log_{10} X \]  

(2)

The exponential value of 2.4 shows that fecundity increases with increase in carapace width. The regression coefficient value between carapace width of the crabs and the total number of embryos carried in the abdomen was found to be highly significant \( (t = 9.908; \ df=205, \ p<0.001) \).

(b) Relationship between fecundity and embryo mass weight
The highest embryo mass weight recorded in the sample was 5.6 g with a total of 170,000 embryos, while the lowest was 0.11 g with a total of 6760 embryos. The total number of crabs observed was 207. The mean embryo mass weight was 1.8 g with a mean fecundity of 74,320 embryos.

The regression line obtained for fecundity and embryo mass weight (Figure 5) was:

\[ \log_{10} F = 4.0 + 1.7 \log_{10} X \]  

(3)

The exponential value of 1.7 shows that fecundity increases with increase in embryo mass weight. The regression coefficient value between fecundity and ovary weight of the crabs was found to be highly significant \( (t=9.55; \ df=205; \ p<0.01) \).

(c) Relationship between fecundity and embryo size
The largest embryo size recorded was in a crab whose embryos measured 0.405 mm in diameter, and its fecundity was 51,506 embryos while the smallest embryo size was
Figure 4. Relationship between fecundity and carapace width of *Thalamita crenata* in Gazi Bay, Kenya (t = 9.908, d.f. = 205, p < 0.001)

Figure 5. Relationship between fecundity and embryo-mass weight of *Thalamita crenata* in Gazi Bay, Kenya (t = 9.55, d.f. = 205, p < 0.001)
Figure 6. Relationship between fecundity and embryo-size of *Thalamita crenata* in Gazi Bay, Kenya (t = 1.04, d.f. = 205, p > 0.05)

0.297mm in a crab whose fecundity was 1520 embryos. The mean embryo size was 0.338mm with a mean fecundity of 74,320. The regression line obtained for fecundity on embryo size (Figure 6) was:

\[ \log_{10} F = 4.24 + 0.0006 \log_{10} X \]  

(4)

The exponential value of 0.0006 shows that there is no significant difference between fecundity and embryo size. The regression coefficient value between fecundity and embryo size was found not to be statistically significant (t=1.04; df=205; p>0.05).

**DISCUSSION**

Crab ovaries are known to undergo colour changes (Spencer, 1932 [in Wild, 1983] ) and increase in mass as they mature as has been observed in *Cancer magister*. Ovarian size and colour are related to histological changes in *Callinestes sapidus* and *Geryon quinquedens* (Wild, 1983). Prasad and Neelakantan (1989) identified four developmental stages of the ovary in *S. serrata* which were recognised using colour changes in the ovary and the oocyte diameter. Pillay and Ono (1978) grouped the developing ovaries of grapsid crabs into four classes based on colour and size of the ovaries, observed with the naked eye. In
this study, it was observed that there is an increase in mass and colour changes in the ovaries of *T. crenata* similar to that observed by Pillay and Ono (1978). All the ovarian maturity stages were observed. Sethuramalingam et al. (1982) identified three stages of ovarian development in *Portunus sinipes* (Miers). They also identified three stages in *T. chaptali*. During the present study, maturity stages of the ovary were based on colour changes which ranged from creamy white to yellow to brown as seen in *S. serrata*. The ovary also increased in mass and the dark grey mass over the ovary in stages 2 and 3 of development was identified as the fatty body accumulation (Onyango, 1995). Because of the crab’s size it was difficult to group the fatty body into sizes and colours. From Figure 2, maturity stage 0 was absent in April, August, June, November and December. This could have been due to the fact that the crabs store sperms for fertilisation, which promoted ovary development immediately after spawning (Erhirarasi and Subramonium, 1980 ([in Prasad and Neelakantan, 1989]). Maturity stage 1 occurred in low percentages while maturity stage 2 was the most abundant in each month. Maturity stage 3 occurred throughout the sampling period. The presence of maturity stages 2 and 3 confirms that this crab is a continuous breeder in the estuary where it occurs. There were some ovigerous crabs with stage 0 ovary development that had carapace width above 35mm. This could have been because they had no sperms in store to stimulate ovary development immediately after spawning. This observation concurred with that of Prasad and Neelakantan (1989) where even larger crabs had to be impregnated more than once for development of the ovary.

Boolootian et al. (1959) reported that eggs of crabs undergo marked colour changes during the course of development. They found that since all eggs of a given individual have been fertilised at approximately the same time and are in synchronous division, only a few eggs representing the 10 developmental stages could be distinguished. In the Dungeness crab *Cancer magister*, the newly spawned egg mass is usually orange in colour (Wild, 1983). In *Scylla serrata*, the newly spawned eggs are completely yellow and compact but as development proceeds with the formation of chromatophores and eyes, egg mass colour changes to greyish-yellow, brownish-black and finally completely dark (Marichamy and Rajapackiam, 1984). During the present study, it was observed that spawned eggs of *T. crenata* are orange-yellow but as development progresses, the embryo mass underwent colour change similar to that observed by Marichamy and Rajapackiam (1984). The eggs of *T. crenata* and *S. serrata* are planktotrophic because they do not have large quantities of yolk characteristic of lecithotrophic eggs and are therefore very small in size (0.344 ± 0.0168mm SE of means and 0.338 ± 0.0187mm SE of means in *S. serrata* and *T. crenata* respectively).

*Thalamita crenata* is a permanent resident in an estuarine habitat. All the 10 developmental stages of embryos were observed; therefore, it appears that the population studied does not migrate out of its habitat. Boolootian et al. (1959) observed that some lower intertidal crabs re-berry themselves a few days after the escape of the larvae.

Female crabs become mature only after they have reached a given size. By collecting large numbers of ovigerous females and measuring their carapace width, this could be
ascertained. The size at which crabs reached sexual maturity is important for conservation of a minimum legal size that may be needed to secure a spawning part of the population (El-zarak et al., 1970).

Sethuramalingam et al. (1982) reported that in *Thalamita chaptali* the size at first maturity was at the size group of 8–8.4mm carapace length but 50% level in maturity was found to be 8.7mm carapace length. During the present study, the smallest ovigerous crab had a carapace width of 28.9mm. The size at first maturity of *T. crenata* at the Kenyan coast was in the size range 40.5–45.5mm carapace width when 50% of the crabs sampled were ovigerous.

Fecundity studies are important for estimating the reproductive capacity of a species. Furthermore, the early stages of an organism contribute a major proportion to the annual production. Bagenal and Braum (1978) reported that fecundity studies give data relating to population stability and yearly class fluctuations which may be a major factor determining variations in production from year to year. Hines (1982) observed that female body size is the principal determinant in reproductive output in brachyuran crabs. Therefore the volume of the body cavity limits the brood size in brachyuran crabs.

Sethuramalingam et al. (1982) studied the fecundities of *T. chaptali* and reported that fecundities ranged from 16,422 eggs in a specimen of 8mm carapace length to 22,694 eggs in a specimen of 28mm carapace length. They observed that a specimen with the same carapace length showed considerable variation in the total number of eggs produced. In *T. crenata* the fecundity ranged from 13,650 embryos in a specimen of 28.9mm carapace width to 207,710 embryos in a specimen of 60.4mm carapace width. Variation in the total number of embryos produced in crabs of the same carapace width was also observed in *T. crenata*. The highest embryo mass weight recorded was 5.6g with a total of 170,000 embryos while the lowest was 0.11g with 6760 embryos. Regression lines fitted for fecundity on carapace width and embryo mass weight were highly significant while the relationship between fecundity and embryo size was not statistically significant. Thorson (1950) pointed out that crabs have high fecundities because there is a wastage of eggs and larvae during development since the larvae are subjected to planktonic and non-planktonic mortality sources such as unsuitable salinities, variation in water temperatures and unsuitable habitats.

**CONCLUSIONS**

In *T. crenata* stage 0 ovarian maturity was observed over most months sampled because there were many immature crabs and crabs which had not copulated following spawning. The presence of maturity stages 2 and 3 throughout the sampling period confirms that *T. crenata* is a continuous breeder. The embryos of *T. crenata* are $0.338 \pm 0.0187\text{mm}$ SE of means in diameter, indicating that this species has planktotrophic larvae. This species does not undertake spawning migrations but remains in the intertidal region of the estuaries where it spawns. This is confirmed by the presence of all developmental stages in the
samples obtained. The smallest ovigerous specimen found had a carapace width of 28.9mm, and the size at first maturity was in the size range of 40.5–45.5mm carapace width. There was a highly significant relationship between fecundity and carapace width and also between fecundity and embryo mass weight. There was a no significant relationship between fecundity and embryo size (t=1.04; df=205; p>0.05).

ACKNOWLEDGEMENT

Sincere thanks to Prof. V. Jaccarini for supervising the research work, the Director of KMFRI for providing the facilities for this study, and the University of Nairobi for a research scholarship. The National Council for Science and Technology provided the grant which made the execution of this project possible, and is sincerely acknowledged.

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Growth and reproduction of the big fin squid, *Sepioteuthis lessoniana*, in the coastal waters of Zanzibar

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ABSTRACT

Aspects of growth and reproduction of the bigfin reef squid *Sepioteuthis lessoniana* (Lesson, 1830) in the coastal waters of Zanzibar were investigated with a view to obtaining basic information that could be used in the management of the squid fishery in the area. A total of 664 specimens, comprising 344 females and 320 males, were collected between April 1994 and March 1995. The size of individuals ranged from 63mm to 347mm and 72mm to 277mm dorsal mantle length (DML) for males and females respectively. Growth was not significantly different (*p*>0.001) between males and females as revealed by length (L)-weight (W) relationship, thus the following expression was used to describe the growth of *S. lessoniana*: \( W=0.0005 L^{2.255} \). Both males and females exhibited allometric growth. Gonad maturation, as revealed by maturity stages and indices, peaked in July, indicating that the spawning period begins around July. Size at maturity was determined by statistical and graphical methods. Size (DML ± 95% CL) at maturity as determined by the statistical method was 138.9 ± 6.4mm and 162 ± 4.3mm for males and females respectively, while the graphical method yielded 149.5mm for males and 162.8mm for females. Fecundity for female individuals ranged from 180 to 1180 eggs with a mean of 680 eggs for individuals of size range 140–249mm DML.

INTRODUCTION

The Cephalopoda which includes the *Nautilus*, cuttlefishes, squids and octopods, is the most advanced class of the phylum Mollusca adapted to a swimming existence. They are exclusively marine, diverse in form, size and nature (Voss, 1973, 1977; Voss and Williamson, 1971; Worms, 1983) and occupy littoral and benthic to pelagic environments of all world oceans. Cephalopods are considerably important as a food resource as well as in scientific investigations (Ngoile, 1987).
Information on the identification of genera, species and brief descriptions on their biology, geographical distribution, habitat and fisheries is obtained from reviews and species catalogues (Boyle, 1983; Caddy, 1983; Voss, 1983; Roper et al., 1984).

The squid of the genus *Sepioteuthis*, belonging to the family Loliginidae, are characterised by wide oval fins that extend almost the entire perimeter of the mantle (Adam, 1939). Four species are presently recognised (Adam, 1939): *Sepioteuthis lessoniana* Lesson, 1830; *S. australis* Quoy and Gaimard, 1832; *S. cepioidea* Blainville, 1823 and *S. loliginiformis* Ruppel and Leuckart, 1828. The genus inhabits inshore waters and is distributed over a broad geographical range that covers the whole Indo-west Pacific, from Japan in the north to New Zealand in the south and Hawaii in the east (Okutani, 1973), Red Sea and the Indian Ocean (Rao, 1954). Bianchi (1985) identified two species of loliginid squid exploited by artisanal fisheries in the coastal waters of Tanzania. These are the Indian squid *Loligo duvauceli* and the veined squid *Loligo forbesii*. However, *S. lessoniana* which is exploited in large quantities in the coastal waters of Zanzibar, was not included in Bianchi's (1985) species identification sheets.

In Zanzibar, *S. lessoniana* is used both as fish bait in hook and line fishery and also for human food. Despite their importance to the people of Zanzibar, very little attention has been paid in studying their biology. Hence, this study was carried out in order to investigate some aspects of the growth and reproduction of the squid *Sepioteuthis lessoniana* in the coastal waters of Zanzibar, with a view to obtaining basic scientific information relevant to management of its fishery.

**MATERIALS AND METHODS**

The study area was at Chwaka Bay at Zanzibar (Figure 1). Chwaka Bay is situated 34km to the east of Zanzibar town. It lies between longitude 39° 31′E and latitude 6° 07′S to 6° 13′S. The bay area is a shallow water body of approximately 35km² and is fringed in the south by a limestone reef which is covered by a dense mangrove forest of approximately 3000ha. A series of tidal creeks drain the forest. None of these waterways has any significant freshwater input except during heavy rains when salinity gradients develop and the creek assumes estuarine characteristics. On the seaward side, immediately adjacent to the forest, the bay opens up to large intertidal flats which are covered by a mixed assemblage of seagrasses and algae or, to a lesser extent, by monospecific seagrass stands. A coral reef, which is part of the extensive reef that fringes the coast of Zanzibar, occurs at the entrance of the bay. Fishing activities are conducted near the reef.

The local climate in Zanzibar is dominated by monsoons—the southern monsoon which prevails from April to October and the northeast monsoon, from November to March. The climate is hot from December to March with average temperature of 28.5°C and cool from June to September with average temperature of 25°C. Heavy rains (long rains) associated with thunderstorms, occur from April to June and light rains (short
rains) occur from October to November. Samples of squid for research were bought from fishermen at Chwaka fish landing station between April 1994 and March 1995. The squid were captured using seine-nets, hook-and-line and spears. Sampling was conducted twice per month preferably during spring tides when squid fishing was quite favourable. Samples obtained were immediately packed in polythene bags and chilled in ice. The samples were then taken to the laboratory and stored in the freezer until analysis.
In the laboratory, samples were thawed at room temperature and later washed with seawater to remove excess mucus. The following linear measurements were taken using a measuring board: dorsal mantle length (DML), fin length (FL) and fin width (FW). For females, nidamental gland length (NGL) was measured to the nearest 1mm after the glands were dissected free from the rest of the body. Gravimetric measurements: body weight (BW), testis weight, ovary weight (OW), and sample ovary weight (SOW) were recorded to the nearest 0.01g using a Sartorius top load balance. The sex of the squid was checked and maturity stage estimated. The maturity stages were classified using a five-point maturity scale that was modified after Ngoile (1987). The description of the maturity scale is given in Tables 1 and 2 for males and females, respectively.

The length-weight relationship was analysed by using individual lengths and weights. Regression of length-weight relationship was assessed by the simple allometric relationship (Gould, 1965):

\[ Y = aX^b \]  

where \( Y \) = total wet weight (g), \( X \) = dorsal mantle length (mm), \( b \) = slope of the log transformed regression line, and \( a \) = intercept on Y-axis. The slopes \( (b) \) for the regression lines for males and females were compared using a modified t-test. The slopes of the regression lines were also used in computations to test for isometry with respect to growth.

Table 1. Male maturity scale for *Sepioteuthis lessoniana* (modified from Ngoile, 1987)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>The reproductive parts in early stage I can only be identified with the aid of a binocular microscope.</td>
</tr>
<tr>
<td>II</td>
<td>All the components of the reproductive system can be seen with the naked eye. The testis is small, translucent and soft. The spermatophoric organ is translucent and easily distinguishable into its components—spermatophoric sac, spermatophoric complex and penis. The opening of the penis is anterior to the base of the left ctenidium. No spermatophores in the spermatophoric sac. The vas deferens is transparent and not easily visible. Hectocotylisation of the fourth left arm has begun.</td>
</tr>
<tr>
<td>III</td>
<td>The testis is large and extends from the posterior tip of the stomach to the posterior apex of the mantle. It is opaque and ridged. The vas deferens is full of sperms and appears creamy white. Spermatophoric complex with a white streak. Spermatophoric sac without functional spermatophores. Penis extends half way the length of the ink sac. Hectocotylisation of the fourth arm easily recognisable.</td>
</tr>
<tr>
<td>IV</td>
<td>The testis extends anteriorly past the posterior tip of the stomach. It is large, opaque and ridged. Spermatophoric sac packed with functional spermatophores. Vas deferens full of sperm. Hectocotylisation complete.</td>
</tr>
<tr>
<td>V</td>
<td>As in stage IV. Penis with spermatophores.</td>
</tr>
</tbody>
</table>
Table 2. Female maturity scale for *Sepioteuthis lessoniana* (modified after Ngoile, 1987)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>The reproductive parts in early stage I can only be identified with the aid of a binocular microscope.</td>
</tr>
<tr>
<td>II</td>
<td>The accessory nidamental glands appear as scarlet specks dorsally to the tips of the nidamental glands. The nidamental gland is opaque. The oviduct and oviducal complex seen as translucent structure and cannot be distinguished from one another. The oviduct opening can be located dorsally to the base of the left ctenidium. The ovary is translucent and appears as fluffy cotton wool emanating from the genital aorta.</td>
</tr>
<tr>
<td>III</td>
<td>The accessory nidamental glands are mottled scarlet and reddish-brown and partly covered by the anterior tips of the nidamental glands. The nidamental glands have increased in size and are opaque. The oviduct is large and translucent. The oviducal gland is opaque. The ova in the ovary can be seen with the naked eye.</td>
</tr>
<tr>
<td>IV</td>
<td>The accessory nidamental glands are mottled scarlet, reddish-brown and orange and are very large. The nidamental glands are large and exude a viscous fluid when cut and squeezed, the anterior tips overgrow the accessory nidamental glands. The oviducal glands are creamy white with a patch of brown at the posterior end. Ovary with ova of different sizes. Free ova found in the body cavity. Spermatheca may contain sperm in which case, it appears as a white spot on the ventral oral area.</td>
</tr>
<tr>
<td>V</td>
<td>Same as IV. Spermatheca with sperm.</td>
</tr>
</tbody>
</table>

The condition factor was calculated for each individual as:

\[
K = \frac{W \times 1000}{DML^3} \tag{2}
\]

where \( K \) = condition factor, \( W \) = total wet weight (g) and \( DML \) = dorsal mantle length (mm).

The gravimetric and linear measurements made on reproductive parts were used in computing maturity indices. The weight of the reproductive part was deducted from the body weight (BW) when computing gonadosomatic index (GSI) which was expressed as follows:

\[
GSI = \frac{GW}{(BW - GW)} \times 100 \tag{3}
\]

where \( GW \) = gonad weight (both ovary and testis).
The other maturity index used was the ratio between nidamental gland length and dorsal mantle length (NGL/DML).

The maturity indices were analysed in terms of mean monthly values for each index and the information correlated with seasonal variation in the maturity stages and the size of squid.

Size at maturity was determined using the graphical and statistical methods described by Udupa (1986) with the size at first maturity defined here as the size (using cumulative frequency distribution) at which 50% of the individuals in the sample are mature (i.e. above maturity stage III). The statistical method involves computations to estimate the mean size and set confidence limits to the estimated mean size.

Fecundity estimates for female squid were conducted using individuals at maturity stages III and IV. Specimens in stages I and II were immature and those in stage V suspected to have shed all the eggs and hence were not included in fecundity estimates. The ovaries of the squid were weighed to the nearest 0.1g and a sample of about 2g was taken from the central portion of each ovary and weighed to the nearest 0.01g. Egg size was measured using vernier callipers. The eggs were freed from the stroma of the sample and sorted into sizes. Eggs of size 6mm were counted for each specimen. The number of eggs in the ovary was estimated as:

\[
\frac{(N \times WOW)}{SOW}
\]

(4)

where, \(N\) = number of eggs in the sub-sample, \(WOW\) = whole ovary weight and \(SOW\) = sample ovary weight. The mean estimate of the number of eggs obtained in all individuals comprise the fecundity estimate of the species. Regression analysis was used to estimate the relationship between fecundity and the length of the squid.

RESULTS

A total of 664 specimens of the squid Sepioteuthis lessoniana were collected during the whole sampling period. All the specimens were used in the analysis of length-weight relationship. The slope (b) for the regression line for males was not statistically different from that of females (0.50<\(p<0.20\)) and hence, both exhibited allometric growth. Since growth was not significantly different (\(p>0.001\)) between males and females as revealed by length-weight relationship (Figure 2), the expression \(W = 0.0005L^{2.555}\) was used to describe the growth of \(S. lessoniana\).

Variation between sexes of specimens of \(S. lessoniana\) was also investigated using Fulton’s condition factor. Visual inspection of the data revealed that females tended to have higher mean condition factor with values exceeding 0.048 except for August. Males had very low values, most of which were below 0.048 for June, July, August, September, October and November (Figure 3).

The maturity indices (GSI and NGL/DML) were used to assess the spawning season of \(S. lessoniana\). The indices (Figures 4 and 5) showed highest mean values during
Figure 2. Length-weight relationship in *Sepioteuthis lessoniana* (sexes combined, N = 664)

\[ y = 0.0005x^{2.5546} \]
\[ R^2 = 0.983 \]

Figure 3. Monthly variation in condition factor for *Sepioteuthis lessoniana*

Figure 4. Monthly variation in mean gonadosomatic index for *Sepioteuthis lessoniana*
May, June and July for both sexes. A minor peak was observed in February for males and March for females. The indices began to drop in June and were lowest in November and December. Comparison in the pattern of seasonal variation of the indices between sexes made through visual inspection show that males mature before females. Within the sex, some indices showed wider peaks than others. The narrowest peak was shown by GSI which had a low value extending from July to January and, therefore, was a better index for assessing the spawning period in *Sepioteuthis lessoniana*.

Determination of size at first maturity was obtained graphically from the curves (Figure 6) and statistically. The results for the computed mean size at maturity are given in Table 3 together with the estimate by graphical means.

Figure 5. Monthly variation in nidamental gland length/dorsal mantle length (NGL/DML) ratio for female *Sepioteuthis lessoniana*.

Figure 6. Size at first maturity of *Sepioteuthis lessoniana*.
The graphical method for males gives an appreciably higher mean size at maturity compared to the statistical method due to the marked inflection of the curve around 89.5–109.5mm (Figure 6). The two methods compare very well for females (Table 3).

The estimated number of eggs varied from 180 to 1180 eggs with a mean of 680 eggs for individuals of size ranging between 140–241mm DML. A linear relationship between fecundity and the body size of the squid existed ($r = 0.47$) as depicted in Figure 7. The maximum diameter of the eggs in the ovary was 6mm.

<table>
<thead>
<tr>
<th>Method</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphical*</td>
<td>149.5</td>
<td>162.8</td>
</tr>
<tr>
<td>Statistical 95% Lower Confidence Limit</td>
<td>132.5</td>
<td>158.6</td>
</tr>
<tr>
<td>Mean size**</td>
<td>138.9</td>
<td>162.9</td>
</tr>
<tr>
<td>95% Upper Confidence Limit</td>
<td>145.7</td>
<td>167.2</td>
</tr>
</tbody>
</table>

*From plots in Fig. 6; **Computed by the method of Udupa (1986).

Figure 7. Relationship between fecundity and dorsal mantle length (DML) of female Sepiotheuthis lessoniana

DISCUSSION

Sexual differences in length-weight relationships in Sepiotheuthis lessoniana were not evident. Comparison of length-weight regression lines for both sexes showed no significant difference (0.50<p<0.20) and hence data were pooled and a regression equation for the combined data used for describing growth of S. lessoniana.

Rao (1954) reported on length-weight relationship of S. arctipinnis (=S. lessoniana) as $W = 0.0005 \ L^{2.449}$ for males and $W = 0.0003 \ L^{2.659}$ for females. He attributed the
difference in length-weight relationship between sexes to: (1) the extent of the development and condition of the gonads and other reproductive organs; (2) the amount of food in the digestive system and the general condition of the tissues, particularly of the mantle which forms the bulk of the weight of the squid. Females extrude large amounts of eggs along with other materials for the formation of capsules. This contributes to the loss of weight in females. Hence, females suffer a greater loss in weight after spawning than the males.

Segawa (1987) reported on the length-weight relationship of wild and cultured S. lessoniana and obtained the regression equations \( W=0.0003L^{2.675} \) \( (r = 0.99) \) and \( W=0.0004L^{2.553} \) \( (r = 0.99) \), respectively. The differences between the two equations were explained as being due to food supply and water condition. The results in the present study indicate that males and females are not different in their growth. This is in contrast to findings by Rao (1954) and Segawa (1987).

The condition factor was higher in females during the period December to May with a decline in subsequent months. Ngoile (1987) observed that mature testes are heavier than mature ovaries and consequently females are heavier than males at equivalent lengths, whereas Cortez et al. (1995) noted that female condition varies as a function of environmental fluctuations and the reproductive cycle. Sexual maturation occurred from March to June with a peak in May and breeding took place in July. Observations by other scientists working on the same species obtained similar results. Segawa (1987) observed that the season of sexual maturation of S. lessoniana around Uchira Bay, Japan was from May to mid or late June. Rao (1954) reported on the same species in South India that sexual maturation takes place from December to February and the spawning period from January to June or July. Small groups of S. lessoniana have been observed laying egg strings among living coral on shallow reefs off the Zanzibar Town during the months of January and June (M. Richmond, pers. commun.).

The ratios GSI and NGL/DML correlated positively with maturation in S. lessoniana. The same observation has been reported for Loligo forbesi (Boyle and Ngoile, 1993). GSI has been shown to be the best index in assessing maturation and identifying spawning period in L. forbesi (Boyle and Ngoile, 1993) and S. lessoniana in the present study. GSI can be computed for both males and females, whereas NGL/DML is useful for females only. The occurrence of sexual maturation in S. lessoniana coincided with peaks of the gonadosomatic index. In both sexes, GSI attained its peak in July implying that most of the individuals were mature especially males who mature earlier than females. O'Dor et al. (1998) observed that sexual maturation does not occur concurrently between the sexes. Breeding takes place from July to September.

Size at maturity that was analysed using the graphical and statistical methods yielded higher values compared to those obtained in South India for the same species by using the graphical method. The sizes obtained by graphical method were 102.5 and 112.5mm DML for males and females, respectively. However, in both cases, males mature at a smaller size compared to females.
The estimated fecundity for female *S. lessoniana* from Zanzibar ranged between 180 and 1180 eggs for individuals of 140 to 249mm DML with a mean of 680 eggs. Choe and Oshima (1961) obtained a higher fecundity estimate of the species in Atsumi Peninsula, Aichi Prefecture, Japan of 1500 to 2000 eggs. Tsuchiya (1981) working on the same species in Okinawa, Japan estimated a much lower fecundity of 86 to 728 eggs. Anon (1975) estimated a low fecundity of the species in the Philippines of 292 to 754 eggs. However, Segawa (1987) observed that female *S. lessoniana* of 200 to 250 mm in mantle length in Kominato, Central Honshu, Japan produced 500 to 1000 eggs in one spawning with a mean of 986 eggs. This estimate is in conformity with that obtained in this study. Anon (1975) observed that ovulation in squids takes place more than once a year in places where there is an extended spawning period and hence low fecundity. Central Honshu and Zanzibar experience a short spawning season (June to July and July to November respectively), and hence high fecundity as compared to Okinawa and Philippines where the spawning period is extended.

Fecundity exhibited a strong relationship with dorsal mantle length \((r = 0.56)\), suggesting that larger individuals at maturity are likely to contribute more offspring to the next generation than smaller individuals. Similar fecundity-size relationship was reported for *Loligo pealei* and fecundity decreased with the progression of months during the spawning season (Vovk, 1972). The size (6mm in length and 4.5mm in breadth) and number (6 to 7) of eggs observed in each capsule for *S. lessoniana* reported in this study are similar to observations on *S. arctipinnis* from Gulf of Mannar by Alagarswami (1966).

REFERENCES


Differential bleaching and mortality of eastern African corals

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ABSTRACT

Coral reefs are increasingly subject to a variety of threats both at the local and global scale. The development of monitoring and assessment tools to diagnose coral reef community responses to threats would assist greatly in the management of their impacts. This paper examines interspecific patterns of bleaching, mortality and recovery of corals on reefs in Kenya, Tanzania, Mozambique and Madagascar for one year after the 1997–98 El Niño weather phenomenon. On average, 50–80% bleaching of corals was observed, with a similar overall proportion suffering mortality. Coral tissue condition (normal, pale, bleached and dead) was recorded for up to one year after the onset of bleaching. Seventeen coral species had sufficient numbers of colonies in each time period for analysis. Cluster analysis and principal components analysis with factor rotation were applied to the dataset, giving 3 major groups of species, characterised by (a) severe bleaching followed by 100% mortality (seen in Acropora spp., Pocillopora spp., Galaxea astreata), (b) graduated bleaching with pale tissue with low to moderate mortality (Porites lutea, Echinopora gemmacea, Hydnophora exesa), and (c) moderate, persistent bleaching with moderate recovery (Pavona varians, Montipora tuberculosa). These species groups based on the bleaching response are consistent with coral life history strategies proposed by other workers.

INTRODUCTION

The El Niño weather phenomenon of 1997–98 was experienced in the western Indian Ocean and eastern Africa in the last months of 1997 and first half of 1998. Heavy rainfall and widespread flooding on land occurred from October 1997 to April 1998, and a 1–2°C rise in the sea temperature from February 1998 was recorded (Figure 1). In the past, extreme El Niño-related impacts to coral reefs have been widely documented in the Pacific and Caribbean (e.g. Williams and Bunkley-Williams, 1990; Glynn, 1993), raising much concern in the Indian Ocean region for the survival of reefs following the recent event (Linden and Sporrong, 1999).
Figure 1. Seawater temperature in shallow coral patch reefs in Kenya, measured using a handheld thermometer during field visits. Curves are 7th-power polynomials to illustrate seasonal cycling. Data is shown for 18 month January–June periods to illustrate two temperature maxima in February–March for each series, for 1992–93, 1993–94 and 1997–98.

Bleaching of corals occurs when zooxanthellae numbers, or photosynthetic pigment concentrations, decrease in response to some stress factor upsetting the coral-zooxanthella symbiosis balance. The term bleaching refers to the coral tissue becoming transparent as a result of lower pigment densities, enabling the white skeleton to show through. The bleaching response is now well recognised as a general response to adverse environmental conditions from a variety of sources, including temperature, irradiance, sedimentation, salinity fluctuations and others (Glynn, 1993). As a general stress response with multiple levels of variation among species and causative factors, bleaching can be investigated as a life history trait with significant importance to the survival of an individual under given environmental conditions.

Organisms can be grouped into a small number of life history strategies that describe characteristic sets of traits adapted to certain types of environmental variation (MacArthur, 1960; Stearns, 1977; Greenslade, 1983). Two predominant sets of life history classes have been developed for a variety of organisms, distinguished by whether they describe two or three basic strategies. Two-strategy models essentially contrast strategies that are favoured during equilibrium versus non-equilibrium conditions (MacArthur, 1960; Pianka, 1970). In predictable, equilibrium conditions where populations are controlled by density-dependent processes such as competition, dominant species are characterised by low rates of increase, and long-lived, large-bodied individuals (K-strategists). Species with the opposite strategy thrive in unpredictable conditions, are controlled by density-independent processes such as disturbance, have high rates of
increase, and very large output of sexual products (R-strategists). Three strategy models add a distinct strategy adapted to adverse, or predictably unfavourable conditions (stress tolerant, or A-strategists, Grime, 1977; Greenslade, 1983). These species have slow rates of increase, low abundance levels and persist through varied environmental conditions. The two-strategy models have strong foundations in theory and modelling as well as empirical evidence (Parry, 1981), while the third strategy is based more on empirical evidence but with little theoretical development. Patterns of bleaching and mortality of corals will be interpreted against the predictions of theory.

The research question underpinning the study reported in this paper was to examine the possibility of using the bleaching response of corals as a real-time indicator of the severity of stress to assist management decision making. Some prerequisites for this type of bioassay approach to bleaching include:

1. The co-occurrence of species with different susceptibilities to stress, such that their stress responses can be quantified and compared under similar environmental conditions, and

2. An understanding of the dynamics of coral bleaching as a stress response in particular with regard to genetic versus environmental components of its expression, and linkages with life history theory.

This study is based on field surveys of coral bleaching and other tissue conditions indicative of stress, conducted from April 1997 to April 1999, on the coast of East Africa. Principal sampling was conducted in Kenya, with repeated sampling of key sites, while other sites in East Africa were sampled when possible. The data presented here are restricted to records of bleaching and mortality observed during and after the El Niño phenomenon of 1997/98.

**METHODS**

Surveys were carried out in coral and hard substrate-dominated patch reefs and fore reef slopes, from the shallow subtidal to 15–20m depth. One-metre-square quadrats were used as the unit of sampling, placed using one of two methods: (a) arbitrary placement of 3 quadrats along each side of 15 m transect lines, and (b) arbitrary placement of quadrats within a defined patch or reef area, dropping the quadrat from 1–3 metres above the bottom. Depending on time available at any one site, 18 to 30 quadrats were sampled. Data recorded included species identification, colony diameter in five size class categories (1: <10cm; 2: 11–20cm; 3: 21–60cm; 4: 61–150cm; 5: > 150cm), and colony condition (percentage of colony tissue that was normal, pale, bleached, or recently dead). The condition categories were defined as follows: normal — healthy tissue appearance; pale — generally pale tissue colour, but not white; bleached —brilliant white tissue colour, sometimes with a tinge of colour such as green or blue, depending on the coral species; and recently dead — colony in growth position and
Table 1. Sampling regions, latitudinal range and effort (in # sites) over intervals before, during and after the El Niño event that started in East Africa about March 1, 1998. Survey intervals are coded as follows: -1, before; 0, during (0–2 months); 1, shortly after (5–7 months); and 2, after (10–12 months)

<table>
<thead>
<tr>
<th>Region</th>
<th># sites</th>
<th>Latitude (°S)</th>
<th>Time intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya - North</td>
<td>11</td>
<td>1.73 – 2.04</td>
<td>-1 3 5 11</td>
</tr>
<tr>
<td>Kenya - Mid</td>
<td>9</td>
<td>3.25 – 3.43</td>
<td>3 4 4 5</td>
</tr>
<tr>
<td>Kenya - South</td>
<td>5</td>
<td>3.97 – 4.33</td>
<td>5 2 – 1</td>
</tr>
<tr>
<td>Tanzania - Zanzibar</td>
<td>2</td>
<td>6.19</td>
<td>2 – – –</td>
</tr>
<tr>
<td>Madagascar - Northeast</td>
<td>7</td>
<td>15.26 – 16.01</td>
<td>– 7 – –</td>
</tr>
<tr>
<td>Mozambique - North</td>
<td>4</td>
<td>12.93 – 16.28</td>
<td>– – – 4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>38</strong></td>
<td><strong>10 16 9 21</strong></td>
<td></td>
</tr>
</tbody>
</table>

corallite structure usually still visible, with an early succession epiphytic community of fine brown filamentous algae, coralline algae and/or grey-brown microbial mat. In general, mortality following mass bleaching was distinguishable from other background forms of mortality due to a covering of very fine, soft, dark brown turf algae, sometimes including a gray bacterial mat, on surfaces with recognisable coral colony morphologies. However after 9–12 months it became increasingly difficult to distinguish cause of mortality, as overgrowth by erect and coralline algae occurred.

Multivariate analyses were conducted using the statistical program JMP 3.0. Initially, coral species were selected for analysis that had greater than or equal to 10 colonies in each sampling interval; however, *Favia pallida, Montipora informis* and *M. tuberculosa* were included to broaden interspecific and generic comparisons.

The 1997–1998 El Niño weather phenomenon in East Africa resulted in a sea temperature rise of 1–2°C in March–April 1998 (Figure 1), resulting in widespread coral bleaching and mortality in the region. Sampling was conducted throughout East Africa (Table 1), with single samples at remote sites and multiple sampling at accessible sites in Kenya. To ease analysis, and based on visual observations of the duration of the bleaching event (approximately 2 months) and recovery over the subsequent 12 months, 4 time periods were identified for grouping of the data: before (t-1), during (t0: 0–2 months), shortly after (t1: 5–7 months) and one year after (t2: 10–12 months) March 1, 1998.

**RESULTS**

Broadly, in the 2 months following the onset of the high temperature event, bleaching between latitudes 0–10°S was at >60% of colonies, decreasing southwards to <10% at some sites over 15°S in Mozambique. Subsequent mortality of corals also fell off, from 40 to 15% over the same latitudinal range.
Figure 2. Number (a) and size (b) of colonies per square metre at each sampling interval. Size classes in (b) correspond to 1: < 10cm; 2: 11–20cm; 3: 21–60cm; 4: 61–150cm; 5: > 150cm

The number of coral colonies recorded per 1m² decreased from the start of the El Niño (t0) until half a year later (t1) due to colony mortality (Figure 2a), but increased to the one year point (t2). Colony size also decreased for the first six months, then continued to decrease for the following six months (t1 to t2, Figure 2b). Both of these patterns were due mainly to fission of older colonies from partial mortality, and to some recruitment of smaller colonies.

The number of normal coral colonies decreased dramatically during the El Niño to approximately 20% of former values (Figure 3a), but there was significant recovery to 60% and above in the following year. Pale and bleached tissue were recorded during the El Niño (20 and 45% respectively) but decreased within 5 months, and mortality increased from about 10% during the El Niño to a high of 30% one year later. Taking into consideration the size and area of coral colonies, the impacts of the bleaching and mortality are higher, with final mortality levels at t2 of 80% and greater, by area (Figure 3b, c). It should be noted that over time, as dead tissue became less recognisable, its proportion is progressively underestimated.

Analysis of species-specific bleaching and mortality patterns was confounded by the large geographic spread of sites, differences in the timing of sampling, and the low abundance of many coral species. Over 50% of all the species were found at less than half the sites (Figure 4), and only 15 to 20 of the 178 species in 48 genera recorded were found at a relative abundance of 1% or greater. Sixteen coral species and the soft coral Sinularia (mainly S. polydactyla) were recorded in sufficient abundance to analyse bleaching, mortality and recovery patterns in the three time periods during and after the El Niño (Table 2).
Figure 3. Proportions of normal, pale, bleached and dead tissue by (a) number, (b) linear dimension (diameter), and (c) projected area of coral colonies. Values for (b) and (c) calculated by using the diameter and area of the approximate mid-point of each size class, assuming a flat circular colony shape (see methods).

Figure 4. Number of sites in which coral species and genera were found. Total number of sites = 38.
Table 2. Sample data: Coral species recorded with sufficient colony numbers at intervals 0, 1 and 2 to enable analysis of bleaching patterns. Mean and standard deviation of tissue conditions during intervals 0, 1 and 2. Also shown are the letter codes used in later figures.

<table>
<thead>
<tr>
<th>Status</th>
<th>Acropora eurystoma</th>
<th>Echinopora gemmifera</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t0</td>
<td>t1</td>
</tr>
<tr>
<td># in colony Normal</td>
<td>29</td>
<td>49</td>
</tr>
<tr>
<td>Mean</td>
<td>0</td>
<td>53</td>
</tr>
<tr>
<td>SE</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>Pale Mean</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>SE</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Bleached Mean</td>
<td>82</td>
<td>4</td>
</tr>
<tr>
<td>SE</td>
<td>29</td>
<td>11</td>
</tr>
<tr>
<td>Dead Mean</td>
<td>15</td>
<td>43</td>
</tr>
<tr>
<td>SE</td>
<td>24</td>
<td>45</td>
</tr>
</tbody>
</table>

Acropora eurystoma (acreur), Echinopora gemmifera (echgem), Favia favus (favfav), Favia pallida (favpal), Favites pentagona (fatpen), Galaxea astreata (galast), Galaxea fascicularis, (galfas), Hydnophora exesa (hydexe), Montipora informis (mtpinf), Montipora tuberculosa (mptub), Pavona varians (pavvar), Platygyra daedelea (pladae), Pocillopora damicornis (pocdam), Pocillopora verrucosa (pocver), Porites lutea (porlut), Porites nigrescens (porpig), Sinularia spp. (zsin)

The mean and standard error of the percentage of each condition at time intervals 0, 1 and 2 were used in the multivariate analyses (Table 2) to incorporate (a) the principal tendency of a species as indicated by the mean, and (b) the stability of its response as indicated by the standard error. Each of these parameters is hypothesised to be a feature of the coral’s life history strategy. Cluster analysis of the data revealed three principal groups each containing two subgroups (Figure 5). The species in each group are listed in Table 3, and the average and standard deviation of tissue conditions at t0, t1 and t2 are shown in Figure 6. In this figure, Group 1 contains corals that had high levels of bleaching at t0 followed by the highest mortality levels approaching 100% at 6–12 months. As an illustration of the severity and extent of mortality in this group, the first time a live Pocillopora damicornis colony was seen following the mortality event in May 1999, was a full year later. Pocillopora verrucosa was separated from the other members of the main Group 1 cluster due to its initially low bleaching levels (<50%). However it also suffered severe mortality. Group 2 is the largest cluster in terms of number of species that showed low levels of initial bleached and pale tissue (approximately 40% together), the highest levels of normal tissue during the bleaching event at about 50%, and relatively low final mortality of about 25% (Group 2.1).
Figure 5. Cluster analysis of the mean and standard error of normal, pale, bleached and dead tissue at intervals 0, 1 and 2, for the seventeen corals shown (Table 4). Groups indicated by numbers above the parent node correspond to Figure 7 and Table 6.

Table 3. Cluster analysis groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Sub-group # species</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td><em>Acropora eurystoma</em>, <em>Galaxea astreata</em>, <em>Pocillopora damicornis</em>, <em>Porites nigrescens</em></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td><em>Pocillopora verrucosa</em></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td><em>Favites pentagona</em>, <em>Favia favus</em>, <em>Galaxea fascicularis</em>, <em>Platygyra daedelea</em>, <em>Porites lutea</em></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td><em>Echinopora gemmifera</em>, <em>Hydnophora exesa</em></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td><em>Favia pallida</em>, <em>Pavona varians</em>, <em>Sinularia spp.</em></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td><em>Montipora informis</em>, <em>Montipora tuberculosa</em></td>
</tr>
</tbody>
</table>

*Echinopora gemmacea* and *Hydnophora exesa* are differentiated into Group 2.2 by having a higher proportion of pale compared to bleached tissue (>50%) during the bleaching event and high mortality (>50%) at the 6-month time interval, compared to species in Group 2.1. Group 3 corals showed initially high levels of pale colour and bleaching and a low proportion of normal tissue, and the lowest levels of mortality at approximately 25% at 12 months. Both groups 2.2 and 3.2 showed higher levels of variation than groups 2.1 and 3.1 respectively, suggesting that these species may have segregated into the subsidiary clusters due to greater variation in their bleaching response.
Figure 6. Cumulative proportions of normal (n), pale (p), bleached (b) and dead (d) tissue at intervals 0, 1 and 2 for the groups identified in Fig. 7 and Table 6 (with standard deviations)
Interpretation of the clusters shown is improved by applying a principal components analysis (PCA) with factor rotation. Figure 7 shows the resulting 3-dimensional plot using the first 3 rotated principal components (RPC) as axes and plotting factor loadings for each coral species. Examination of the component loadings for each axis with respect to each variable in the analysis (i.e. mean and variation of each tissue condition at each interval) enables an interpretation of the main variables associated with high positive and negative values of each axis (Table 4). The three PC axes address different components of bleaching and mortality in the coral species sampled. Between-group comparisons of the bleaching response and mortality trends is enhanced in the rotated factor PCA (Figure 7) over the cluster analysis (Figure 5) by the clearer multidimensional spatial relationships shown by the species points and their rays.

Figure 7. Principal components analysis with factor rotation. The first 3 rotated factors form the x, y and z axes respectively. Solid rays to the species points represent positive values on the z axis (i.e. out of page), dashed rays indicate negative z values (i.e. into the page). Species names corresponding to abbreviations used are given in Table 2.
Table 4. Interpretation of the principal components analysis with factor rotation (Reification refers to the physical meaning ascribed to the axis)

<table>
<thead>
<tr>
<th>Axes</th>
<th>Component loadings</th>
<th>Interpretation</th>
<th>Reification</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>+ve High values and variation in normal tissue at t0 and t2. High incidence of pale tissue at t0.</td>
<td>Light to moderate bleaching at initial stress, low levels of subsequent mortality.</td>
<td>Relation between severe bleaching and mortality</td>
</tr>
<tr>
<td></td>
<td>-ve High bleaching levels at t0 and high mortality at t2.</td>
<td>High degree of bleaching at initial stress, followed by high mortality.</td>
<td></td>
</tr>
<tr>
<td>y</td>
<td>+ve Variable mix of normal, pale, bleached tissue, no mortality.</td>
<td>Variable bleaching response, no mortality.</td>
<td>Mortality patterns (partial vs. full)</td>
</tr>
<tr>
<td></td>
<td>-ve High mortality t1 and t2; high variation in mortality at all times.</td>
<td>High and variable mortality levels.</td>
<td></td>
</tr>
<tr>
<td>z</td>
<td>+ve High levels of bleaching at all times.</td>
<td>High, persistent bleaching response.</td>
<td>Chronic, low level bleaching patterns</td>
</tr>
<tr>
<td></td>
<td>-ve Mostly normal or pale at t0 and t1</td>
<td>Low bleaching response.</td>
<td></td>
</tr>
</tbody>
</table>

Along the x axis, coral species in Group 1 (especially 1.1) are strongly segregated from the other species. Group 1 species bleached immediately and severely at the onset of seawater warming (Table 5, Figure 6). Most suffered 100% mortality (Pocillopora damicornis, Acropora eurystoma, Porites nigrescens and P. verrucosa) following bleaching, while Galaxea astreata suffered, in general, 90–100% mortality, with slow death of tissue fragments through both t1 and t2. By contrast, all the other species showed varied levels of bleaching and varied mortality, and are more separated from each other by variation in the y and z axes. All corals in Group 1 are fast growing species capable of monopolising space (Acropora spp., G. astreata) and/or rapid opportunistic colonisation of available space (Pocillopora spp., Porites nigrescens).

The y axis segregates species according to the degree of mortality experienced during and after bleaching, relatively independently of their bleaching response. Species that showed low levels of mortality (Pavona varians, Favia palilda, Sinularia spp.) are placed at high positive values of the y axis, with increasing mortality recorded in species towards high negative values (Echinopora gemmifera, Hydnomphora exesa, Pocillopora verrucosa).

The z axis mainly distinguishes the two Montipora species from the others. These were found to exhibit some level of bleaching throughout the surveys, even after other species had recovered or died. Low level chronic bleaching of Montipora spp. has been observed before (pers. observ.) independently of temperature or other obvious stress factors. The z axis may therefore relate to the long-term tendency for colonies of a species to bleach under normal variation in environmental conditions.
Table 5. Coral reef clonal invertebrate strategies. Sources selected are those that have specifically addressed strategies among reef organisms. Possible strategies are interpreted from the descriptions as given by the authors in relation to life history strategies: K - equilibrium, and r - opportunistic (MacArthur, 1960); A - adversity and C - competitive (Greenslade, 1983; Grime, 1977)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
<th>Species</th>
<th>Possible strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bak and Engel 1979 (Caribbean)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy 1</td>
<td>low recruitment, high juvenile and adult survivorship, low partial mortality/fragmentation, long life expectancy, large adult size, competitively aggressive, resistant to sediment, high regenerative abilities.</td>
<td>Montastrea annularis</td>
<td>K(C)</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>high recruitment, low juvenile and adult survivorship, small adult size, high rates of partial mortality, low competitive abilities, low regenerative abilities.</td>
<td>Agaricia agricites</td>
<td>r</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>low recruitment, high survivorship of juveniles, high fragmentation of adults, high vegetative reproduction, high regenerative abilities, fast growth rates.</td>
<td>Acropora palmata</td>
<td>K</td>
</tr>
<tr>
<td><strong>Jackson and Hughes 1985 (Caribbean)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy 1</td>
<td>slow growth rates, large colony size, high survivorship, good regenerative abilities.</td>
<td>Montastrea annularis (shallow water)</td>
<td>A</td>
</tr>
<tr>
<td>Strategy 1b</td>
<td>foliaceous, slow growth, good competitive abilities, robust skeleton, low tissue turnover rates, low mortality, low recruitment.</td>
<td>Montastrea annularis (deep water)</td>
<td>K</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>foliaceous, fast growth rates, low competitive ability, high fragmentation, high tissue turnover rates, high mortality, high recruitment.</td>
<td>Leptoseris cuculliata</td>
<td>r</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>fast growth rates, poor competitors, high fragmentation and juvenile survival, long lived, but possibly undergo senescence in older parts, only young colony portions efficient regenerators.</td>
<td>Acropora cervicornis</td>
<td>K(C)</td>
</tr>
<tr>
<td><strong>Kojis and Quinn 1994 (Indo-Pacific/Caribbean)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy 1</td>
<td>slow growth rates, large, massive colonies, significant reef builders. Gamete spawning with low to intermediate recruitment. Asexual fragmentation important.</td>
<td>Montastrea annularis</td>
<td>A</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>high recruitment rates of brooded larvae, rapid growth, small adult size.</td>
<td>Pocillopora damicornis, Agaricia spp.</td>
<td>r</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>fast growth rates, high reproduction through fragmentation and/or gamete spawning enable monopolisation of space</td>
<td>Acropora spp.</td>
<td>K(C)</td>
</tr>
<tr>
<td><strong>Cameron and Endean 1985 (Indo-Pacific)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy 1</td>
<td>Persistence selection: adaptations to low abundances, persistence through varied environmental conditions</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>Reproduction selection: opportunistic, fast growth rates, high sexual and/or asexual reproduction, monopolise space in short term. High turnover.</td>
<td></td>
<td>r/K</td>
</tr>
</tbody>
</table>
DISCUSSION

Coral bleaching and mortality resulting from the 1997–1998 El Niño phenomenon affected the entire coast of East Africa, with average mortality levels of 50–80% and individual locations suffering close to 100% mortality. In general bleaching and mortality were lower at higher latitudes in southern Mozambique (at 10–30% at some sites, Schleyster et al., 1999). The bleaching event in East Africa is likely to have started on the east coast of Madagascar in February 1998 (McClanahan and Obura, 1998), progressing northwards with the intertropical convergence zone (ITCZ) as it moved into the northern hemisphere, with the first bleaching observed in northern Kenya around 21 March 1999. In Kenya, corals were highly bleached for up to 2 months, with increasing mortality noted from April–June 1998, and prolonged degradation and mortality of apparently recovering tissue occurring up to November/December 1998.

Bleaching and mortality also apparently affected all or most corals, and also impacted soft corals, anemones, clams, and other photo-symbiotic invertebrates. Only 9 coral species out of a total of 178 (5.1%) showed no evidence of bleaching or mortality during the surveys, the following with 5–11 colonies recorded *Goniopora stokesi, Alveopora allingi, Coscinarea columna, Blastomussa merletti* and the following with <3 colonies observed: *Coscinarea exesa, Goniopora fructicosa, Stylocoeniella sp., Siderastrea savignyana, Leptoseris explanulata*. The poritids *Goniopora* and *Alveopora*, and the genus *Coscinarea* were recorded in sufficient numbers to confirm a low tendency to bleaching and mortality.

Quadrats were sampled randomly, and from different locations and reef sites, thus the number of colonies per square metre can be expected to show high variation. Nevertheless, a clear loss of colonies was recorded from $t_0 - t_1$ due to mortality (Figure 2a), and subsequent increases in colony number from $t_1 - t_2$ were due in part to recruitment, and to partial mortality following bleaching, resulting in fission. Over the entire survey period, the area of living coral tissue surfaces decreased by 80% (Figure 3c).

The principal objective of this study was to determine if useful indicator variables can be identified to infer the type and level of stress from coral bleaching patterns. The multivariate analyses revealed three major groupings of corals according to their bleaching and mortality patterns, with minor subgroups within these. These are summarised in Table 6 with respect to potential life history strategies. Group 1 shows low resistance to the high temperature event and high mortality, with highly constrained responses among the species (Figure 7). By contrast, groups 2 and 3 show higher resistance to stress and more variable responses.

The principal thesis of this study is to propose stress resistance, i.e. bleaching and mortality vs. recovery, as a reasonable basis for constructing life history strategies. Until now, the principal efforts to group corals and other coral reef organisms into life history strategy groups, have focused on demographic parameters (Table 6), reflecting the influence of classical life history theory and plant demography on coral reef ecology.
Table 6. Bleaching and mortality patterns shown by species groups, and possible stress resistance strategy types. Primary species can potentially dominate local reef areas, secondary species usually in small numbers

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major properties</td>
<td>Severe bleaching response followed by 100% mortality.</td>
<td>Graduated bleaching response with pale tissue, moderate mortality and recovery.</td>
<td>Moderate, persistent bleaching, moderate mortality, some recovery.</td>
</tr>
<tr>
<td>(sub-group 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy type</td>
<td>Low stress resistance, fast growth and over-growth capability, primary species.</td>
<td>Moderate to high stress resistance, some primary species.</td>
<td>Moderate to high stress resistance, primary species.</td>
</tr>
</tbody>
</table>

Thus recruitment, survivorship and competitive ability formed the cornerstone of Bak and Engel’s (1979) work, growth rate, competitive ability and regeneration were considered by Jackson and Hughes (1985), and growth rate, reproduction and adult colony size were considered by Kojis and Quinn (1984). All of these authors identified three primary life history strategies for corals. It is important to note that the clonal nature of corals and many other sessile, shallow marine invertebrates sets them apart from a clonal animals in fundamental respects (indeterminate growth and size-related life history traits) that invalidate the use of many life history models developed for a clonal animals (Jackson and Hughes, 1985). Nevertheless parallels are evident between coral strategies and the classic r-K strategies (MacArthur, 1960, Table 7).

The bleaching and mortality strategies proposed for corals in this study (Table 6) exhibit some parallels to the strategies in Table 5 and outlined in the introduction. Group 1 conforms most closely to the K-strategies of fast growth coupled with poor performance in unpredictable situations such as the El Niño event reported here. Groups 2 and 3 are less well defined on the basis of bleaching and mortality characteristics alone, and it may be premature to ascribe them on this basis alone to the strategies developed by others. However the addition of other known traits for the species in the groups, such as the large colony size and potential dominance of Group 2 corals in marginal or high-sediment environments in East Africa (Hamilton and Brakel, 1984; McClanahan and Obura, 1997; Obura, 1995) suggests these correspond loosely to long-term persistence strategies (A-strategists). The small colony size and secondary nature of Group 3 corals in normal conditions in East Africa suggests these may correspond to the opportunistic strategy of reproduction maximisation (r-strategists). As implied in this paragraph, additional characters can be used to make the assignment of life history strategies based on stress resistance more robust (such as by adding maximum colony size or other demographic parameters), and more comparable to past work.
<table>
<thead>
<tr>
<th>Source(s)</th>
<th>Strategy 1: Equilibrium</th>
<th>Strategy 2: Opportunistic</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>MacArthur 1960,</td>
<td>Equilibrium selection: density-dependent populations, low rates of increase, thrive in</td>
<td>Reproduction selection: density independent population control, high rates of increase, thrive in unpredictable conditions.</td>
<td>N/A</td>
</tr>
<tr>
<td>Pianka 1970</td>
<td>predictable conditions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whittaker 1975,</td>
<td>as above</td>
<td>as above</td>
<td>Adversity selection: adaptation to predictably unfavourable environments. Slow rates in increase, low abundance, persistence.</td>
</tr>
<tr>
<td>Greenslade 1983</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The axes of the principal components analysis (Figure 7, Table 4) dissect the bleaching and mortality responses of the coral species into several components, offering hypotheses for further investigation into the nature of bleaching. The first principal component (x axis) defines the dominant patterns in bleaching and mortality, separating high bleaching/high mortality corals from all the others. The unifying character of these corals is their branching (and columnar, in the case of *Galaxea astreata*) morphology and rapid growth rates, suggesting that growth rate and resistance to at least high temperature stress are a direct physiological tradeoff. The second principal component (y axis) identifies the next dominant pattern in the dataset, that there is not a direct relationship between bleaching and mortality for all coral species — i.e., conditions that induce bleaching and mortality in one species may induce less or more of either response in other species. This axis focuses attention on the role of bleaching relative to mortality, and its possible roles for a coral. The third principal component raises a similar question but in relation to bleaching alone, in that it separates corals with 'high-intensity' responses (i.e. with high levels of bleaching) from those with 'low-intensity' responses (i.e. showing only a paling of tissue, if anything). Why do different species have different levels of response to the same stimulus? These issues need to be explored to better understand the nature of bleaching in corals.

In terms of coral reef assessment and monitoring, the construction of coral life history strategies based on easily observable and real-time parameters such as the degree of bleaching and recovery or degradation processes, could make a significant

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contribution to coral reef management. Indicator coral species could be characterised according to their life history strategy, allowing predictions to be made as to their response to any given set of threats. Testing these predictions through observation in the water could be used to signal the status of the reef. This is essentially a form of bioassay, using organisms as indicators of environmental health based on a knowledge of their behaviour under specified stressful or less-than ideal conditions. The advantages offered by using life history theory are related to the ability to test hypotheses or predictions, as opposed to simple monitoring, and to select sets of species and strategies to compare and contrast their responses which should vary in accordance with theory.

Based on the findings of this study, a selection of 10 easily identifiable corals from the 3 empirical groups could form the basis for a reef monitoring strategy:

- **Group 1** (K strategists — vulnerable to unpredictable environmental variation) — *Acropora eurystoma, Pocillopora damicornis, Galaxea astreata;*
- **Group 2** — *Favia favus, Galaxea fascicularis, Platygyra daedelea, Porites lutea, Echinopora gemmifera;*
- **Group 3** — *Pavona varians, Sinularia spp., Montipora tuberculosa.*

Groups 2 and 3 are not ascribed to a strategy yet, as results were not conclusive enough to distinguish these. Further research is needed to explore the usefulness and applicability of these strategy sets.

Such a coral bioassay could be useful for management in two basic ways: (a) by monitoring randomly selected colonies of the given suite of coral species on reefs under consideration, and (b) by transplanting pieces of corals of these species as controlled test subjects, to monitor the effects on them of the local environment. This latter method has the advantage of being able to control genetic variability of the bioassay organisms, and to use individuals of known genetic and phenotypic character. In both cases, corals in pristine (or control) conditions need to be monitored as a standard for comparison. Patterns of bleaching and mortality, and other relevant variables such as growth rate, would be monitored to infer the level of stress to the reef in general, and help inform management decisions.

ACKNOWLEDGEMENTS

This research was funded by the National Geographic Society, with additional support in funds, logistics or equipment from the Rockefeller Foundation, Coral Reef Conservation Project, Wildlife Conservation Society, CARE International (Mozambique), CORDIO, MICOA (Mozambique) and Lifting Equipment Co. Ltd. (Mombasa). Approval for research in Kenya was provided by the Office of the President, Kenya.
REFERENCES


Existence of potentially harmful microalgae in coastal waters around Zanzibar: A need for a monitoring programme?

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ABSTRACT

A nine-month survey of potentially harmful microalgae was carried out in the coastal waters around Unguja Island, Zanzibar, from September 1998 to June 1999. Using a light microscope, more than 20 species were identified. These were distributed among three major microalgal groups: the cyanobacteria, mostly dominated by *Trichodesmium* spp; the dinoflagellates, dominated by *Prorocentrum* spp. and *Gambierdiscus toxicus*; and the diatoms, mostly *Pseudo-nitzschia* spp. This and other preliminary studies indicate the presence of harmful microalgae in Zanzibar waters. Further studies to assess both spatial and temporal distribution, as well as potential ecologic and economic effects, are recommended.

INTRODUCTION

Phytoplankters, which are predominantly autotrophic, are the primary producers of organic matter in aquatic habitats. Like plants on land, these are the basic food in the sea for consumers such as zooplankton and fish. The phytoplankton thus stand on the baseline of many food webs in aquatic environment (Boney, 1975). Some planktonic genera, especially those belonging to the cyanobacteria, e.g. *Trichodesmium*, *Richelia* and *Nostoc* spp., are able to fix nitrogen, hence contributing to the rise of nitrogenous nutrients in the marine environments (e.g. Bryceson, 1977; Carpenter, 1983).

The population of Tanzanian islands such as Mafia, Unguja and Pemba as well as the dwellers along the entire coastline of Tanzania is heavily dependent on fish obtained from a variety of local habitats as the primary source of animal protein. Hence, it is vulnerable to microalgal-borne toxins, which could be present in reef, open sea, seagrass beds and mangrove areas.

Sometimes blooms of toxic phytoplankton occur, especially in coastal waters of tropical seas (Quod and Turquet, 1996; Orellana-Cepeda, 1996; Wyatt, 1998). This may cause massive fish kills and contamination of shellfish with the consequent death
of other marine life as well as terrestrial animals (Boney, 1975; Habermehl et al., 1994; Ochoa et al., 1996). Biotoxins produced by some dinoflagellates are accumulated via the food chain by herbivorous and carnivorous fish (Qoud and Turquet, 1996). For example, ciguatera fish poisoning is the term introduced to a well-documented disease from the Pacific, the Indian Ocean and Caribbean Sea (e.g. Ruff and Lewis, 1994). The commonly bloom-forming cyanobacteria *Trichodesmium thiebautii* has also been reported to be toxic to calanoid and cyclopoid copepods (Hawser et al., 1992).

Potentially harmful microalgae are normally found occurring in low numbers, but under certain conditions may form extensive blooms that can have devastating effects on the environment (Moestrup and Larsen, 1992). Some species however, such as *Dinophysis* spp. can cause serious problems even at moderate biomass (Hallegraef, 1995). Several potentially harmful microalgae have so far been found to exist in Tanzanian coastal waters (Bryceson, 1977; Lugomela, 1996) though their relative abundance and spatio-temporal variability is not well assessed. Probably the first report of potentially harmful microalgae in Zanzibar waters is that of Ballantine (1961) who recorded several dinoflagellates, including *Gymnodinium chukwanii* named after Chukwani village just south of Zanzibar town. Lugomela (1996) reported about eight species of potentially harmful microalgae. These include the cyanobacteria *Trichodesmium*, *Schizothrix* and *Anabaena* spp.; the dinoflagellates *Prorocentrum lima*, *Dinophysis caudata* and *Osteriopsis lenticularis*; and the diatom *Pseudonitzschia* sp. as well as the haptophyceae *Prymnesium parvum*.

The present study aims at surveying and documenting the occurrence of harmful microalgae in different habitats (mangrove, coral reef, Zanzibar Port and open ocean areas) in waters around Unguja Island in Zanzibar.

**MATERIALS AND METHODS**

**Study area**

Four stations were established to represent a range of ecosystems (Figure 1). The first two stations were at Chwaka Bay, i.e. about 34km to the East Coast of Unguja Island. The Bay is a shallow water body and has an average depth of 2m at mean sea level. It covers an area of approximately 35km² and is fringed to the south by a limestone reef platform covered by a dense mangrove forest of approximately 3000ha. A series of tidal creeks drain the forest, and these include Mapopwe Creek, where station I was located. On the seaward side, immediately adjacent to the forest, the Bay opens up to larger inter-tidal flats, which are covered by mixed assemblages of seagrasses and algae. Seaweed farming is also practised in this area, and station II was located there. Stations III and IV were located to the West Coast of Unguja Island off Zanzibar Town. Station III was just off Zanzibar Town, near Zanzibar ferry port, where there are several sewage outlets. Station IV was about 6km from the shoreline, on the coral reef area near Bawi Island.
Sampling procedures and laboratory analysis

Duplicate samples for qualitative analysis were collected regularly, once a month (first week of the month), from each station for a period of nine months. A plankton net of mesh size 20μm was used during sample collection. At the deeper stations (Sta. III and IV), the net was lowered to a depth of about 15m and vertically hauled. At stations I and II, with an average depth of 2m, samples were collected by surface towing of the net. Out of the duplicate samples, one was immediately fixed with Lugol’s solution while the other was brought to the laboratory for analysis of live material. Both samples were examined under a light microscope.

Benthic species were collected by scuba diving. However, this was carried out only at station IV, during the months of February, April, May and June 1999. Dead
corals with algal tufts were hand-picked and placed into plastic bags. In the laboratory, the corals were brushed with a stiff household brush to remove the organisms from the substrate. Next, the water was filtered through an 850 μm sieve to remove rubble and other coarse particles. Larger seaweeds were also collected in plastic bags. In the laboratory the samples were shaken vigorously and then filtered through an 850 μm sieve to remove the larger particles. The collected seawater was then examined under the light microscope.

RESULTS AND DISCUSSION

Several phytoplanktonic and benthic species were identified during the 9-month sampling period. Some of the species are potentially harmful, while others are harmless. The results are summarised in Tables 1, 2 and 3.

Many of the phytoplankton species identified during this study were diatoms (Table 1). Fortunately, most of the diatoms are not known to be harmful. Of the 40 species of diatoms observed during the study period, only one potentially harmful diatom, *Pseudonitzschia* spp., was identified (Table 1). This genus has several members known to be toxic (Hasle and Fryxell, 1995). The toxic *Pseudonitzschia* species cause amnesiac shellfish poisoning, the symptoms of which include gastrointestinal and neurological problems as well as persistent loss of short-term memory.

Dinoflagellate is the group with the largest number of harmful species (Taylor et al., 1995). In this study, a total of 26 dinoflagellate species (Table 2) were identified, out of which 19 species are known to be potentially harmful. These include 10 species of the genus *Prorocentrum*, which were mostly found at station IV in the benthic fraction. Others include *Amphidinium* spp.; *Ostreopsis* spp., *Gambierdiscus toxicus*, *Coolia* (cf. *Monotis*) and *Gonyaulax* spp. *Prorocentrum* species are known to produce okadaic acid which is a diarrheic shellfish poison (Rhodes et al., 1995). *Prorocentrum lima* has also been associated with ciguatera syndrome (Faust, 1991).

*Gambierdiscus toxicus* is the major contributor to ciguatera syndrome. This species produce lipid-soluble ciguatoxins (Legrand et al., 1992). A new ciguatoxin-producing benthic dinoflagellate named *Gambierdiscus yasumotoi* has recently been isolated from macroalgae in the fringing reef surrounding the Singapore Island (Holmes, 1998). In the Indian Ocean, ciguatera was first described in Mauritius (Halstead and Cox, 1973, cited in Quod and Turquet, 1996). In Reunion, for example, 81% of the poisoning cases are due to ciguatoxins. A severe poisoning occurred in the West Coast of Madagascar in 1994 where ciguatera had not been reported before (Habermehl et al., 1994). *Gambierdiscus toxicus* was also observed in the benthic microalgae at station IV. A study by M. Silver (unpublished preliminary report) and that by J.P. Quod (unpublished data) also indicated the presence of *G. toxicus* at a location close to Zanzibar port and Bawi Island respectively. Other dinoflagellate species observed in this study which are possible contributors to ciguatera fish poisoning include *Amphidinium* spp., *Ostreopsis* spp. and *Coolia* spp.
Table 1. List of diatoms observed between September 1998 and June 1999 for Stations I, II, III and IV

<table>
<thead>
<tr>
<th>Species identified</th>
<th>Month observed</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>O</td>
</tr>
<tr>
<td>Amphora spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Asterionella spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacillaria spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Bacterium spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Chaetoceros spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cosnodiuncus spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cylindrotheca spp.</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Dicyota spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Diploneis bombus</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ditylum brightwerti</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Eucampia spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Guinardia flaccida</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Guinardia spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Gyrosigma spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hantzschea spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Hemiaulus spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Isthmia spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lauderia annulata</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Leptocylindrus spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Licmophora spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Mastogloia spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Navicula spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nitzchia longissima</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nitzchia sigma</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nitzchia spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Odontella sinensis</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rhabdonema spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Pleurosigma spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pseudo nitzchia spp.*</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Rhizosolenia alata</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Rhizosolenia crassipisna</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rhizosolenia cylindrus</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Rhizosolenia delicatula</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rhizosolenia hebata</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rhizosolenia stolterforthii</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rhizosolenia spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Schroederella spp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Synedra spp.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Thallassiothrix frauenfeltii</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Thallassiothrix spp.</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

*Potentially harmful species.
Table 2. List of dinoflagellates observed between September 1998 and June 1999 for Stations I, II, III and IV

<table>
<thead>
<tr>
<th>Species identified</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>J</th>
<th>F</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Amphidinium carterae</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Amphidinium klebsii</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Amphidinium opeculatum</em></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Ceratium furca</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>III, IV</td>
</tr>
<tr>
<td><em>Ceratium fusus</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>I, III, IV</td>
</tr>
<tr>
<td><em>Ceratium pentagonum</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>III</td>
</tr>
<tr>
<td><em>Ceratium spp.</em></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III</td>
</tr>
<tr>
<td><em>Coolia (cf. Monotis)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Gambierdiscus toxicus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>IV</td>
</tr>
<tr>
<td><em>Gonyaulax spinifera</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Gonyaulax spp.</em></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>II, IV</td>
</tr>
<tr>
<td><em>Gymnodinium spp.</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>IV</td>
</tr>
<tr>
<td><em>Ostreopsis heptagona</em></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Ostreopsis ovata</em></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III, IV</td>
</tr>
<tr>
<td><em>Ostreopsis spp.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum belizeanum</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum borbonicum</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum concavum</em></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II, IV</td>
</tr>
<tr>
<td><em>Prorocentrum elegans</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum emarginatum</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum lima</em></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II, IV</td>
</tr>
<tr>
<td><em>Prorocentrum maculosum</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum mexicanum</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td><em>Prorocentrum micans</em></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II</td>
</tr>
<tr>
<td><em>Prorocentrum spp.</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>II, IV</td>
</tr>
<tr>
<td><em>Protoperidinium spp.</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>II, III, IV</td>
</tr>
</tbody>
</table>

*Potentially harmful species.

For ciguatera toxins, there are about 150 symptoms and all are difficult to diagnose (Turquet, pers. commun.). The general symptoms caused by ciguatoxins include digestive problems, neurological problems, respiratory difficulties and skin irritation. However, the most important symptoms are strong itching, tiredness, tingling sensations, diarrhoea, inverse sensation, respiratory difficulties and dental pain. At low doses, only the digestive symptoms occur.

In the cyanobacteria group, a total of 10 species were identified (Table 3), out of which 4 species are potentially harmful. *Trichodesmium* spp. were commonly observed and have been reported to form blooms in Tanzania waters (e.g. Bryceson, 1977; Lyimo, 1995; Lugomela, 1996). When abundant and decaying, *Trichodesmium* produces an unpleasant smell and pinkish colour and has been shown to be toxic to some shrimps (Taylor, pers. commun.). *Trichodesmium thiebautii* has been shown to possess a neurotoxin...
Table 3. List of cyanobacteria observed between September 1998 and June 1999 for Stations I, II, III and IV

<table>
<thead>
<tr>
<th>Species identified</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>J</th>
<th>F</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyngbya spp.*</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III, IV</td>
</tr>
<tr>
<td>Nostoc/Anabaena spp.*</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td>Oscillatoria spp. *</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>II, III, IV</td>
</tr>
<tr>
<td>Plectonema spp.</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Richelia intracellularis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>III, IV</td>
</tr>
<tr>
<td>Spirulina spp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td>Trichodesmium erythraeum</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III, IV</td>
</tr>
<tr>
<td>Trichodesmium tenue*</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td>Trichodesmium thiebauii</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>III, IV</td>
</tr>
<tr>
<td>Trichodesmium spp.</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II, III, IV</td>
</tr>
</tbody>
</table>

*Potentially harmful species.

and has been reported to be toxic to some marine invertebrates such as calanoid and cyclopoid copepods (Hawser et al., 1992). Furthermore, there are reports of breathing difficulties to people who have been near red tide blooms of *Trichodesmium* (Carpenter and Carmichael, 1995). Another potential harmful cyanobacteria observed was the *Anabaena* spp., which is associated with neuromuscular blocking alkaloid anatoxin and paralytic shellfish poisoning (Carpenter and Carmichael, 1995).

Some examples of cyanobacterial toxic blooms and scums such as those of *Microcystis, Anabaena, Oscillatoria* and *Aphanizomenon* species have been observed in several parts of the world (e.g. Sivonen et al., 1990; Scott, 1991; Yoo et al., 1995). Similarly, several saxitoxins have been found in mats and cultures of freshwater *Lyngbya wollei*, in Alabama, USA (Carmichael et al., 1997). In addition, new types of toxins, the microcystins, have been characterised from four strains of *Oscillatoria agardhii* and *Nostoc* strains [Sano and Kaya, 1995; Beattie et al., 1998 (both cited in Codd and Bell 1998)]. Health hazards related to cyanobacterial toxins could be seen in both animals and human beings, and may be attributed to drinking contaminated water or through recreational activities. Toxins like anatoxin-a and microcystins have been identified in affected animals, such as in dog stomach contents, sheep rumen contents and stomach contents of poisoned birds (Edwards et al., 1992; Lawton et al., 1995; Henriksen et al., 1997). In southeast China, microcystins have been linked to elevated rates of primary liver cancer in humans (Codd and Bell, 1998).

Large blooms and scums of cyanobacteria, like those of *Microcystis* and *Anabaena*, could be stimulated by land disturbances such as construction and filling of reservoirs, which increase eutrophication in catchment water body (Harper, 1992). An example is the event observed in Itoparica Dam, Bahia, Brazil in 1998, causing about 2000 gastroenteritis cases, with a death toll of 88 individuals (Codd and Bell, 1998). In another case that occurred in Caruaru, NE Brazil, 126 people were affected after using water from a lake with massive growth of cyanobacteria. The victims developed symptoms
of acute neurotoxicity and sub-acute hepatotoxicity. Out of the 126 people affected, 60 died (Pouria et al., 1998; cited in Codd and Bell, 1998).

CONCLUDING REMARKS

Zanzibar coastal ecosystems are now experiencing great interference from human activities such as uncontrolled cutting of mangrove trees, the dumping of untreated sewage in coastal waters and destructive fishing activities in coral reef areas. All these could accelerate the rise of toxic microalgae such as Gambierdiscus toxicus. In addition, the fast-growing population of Zanzibar (currently at a rate of 5% per annum) and the increased influx of tourists also impart a significant pressure/stress on the coastal environment. This stress could again result in changes of water quality, and consequently the associated biota.

Therefore, it is not surprising that several species of potentially harmful microalgae have been observed in Zanzibar waters. Our results, and those of the previous studies, show without doubt that potentially harmful microalgae do exist in Zanzibar waters. To what extent do they affect the seafood, the consumers and the economy? What is the biomass, productivity and seasonality of these species? What causes them to occur? These are some of the questions that need to be answered. As such, this calls for a detailed study to assess their spatial and temporal distribution. Alternatively, a monitoring programme could be put in place. This would lead to a better understanding of factors that control the abundance and distribution of harmful microalgae, with the aim of controlling the possible impacts on the fishery and seafood consumers.

ACKNOWLEDGEMENTS

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The 1998 coral bleaching and mortality event in Tanzania: Implications for coral reef research and management

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ABSTRACT

Bleaching and mortality of corals occurred in many reef areas along the Tanzanian coast between March and June 1998 at varying levels of severity among different sites. The corals of Tutia and Mange reefs of Mafia Island, and those of Misali of Pemba Island suffered greater mortalities ranging from 60–90% and 30–65% respectively. Reef corals in Mnazi Bay, Kunduchi and Songo Songo experienced medium to high coral mortalities. Reefs around Unguja Island were the least affected, with coral mortality ranging from 10–25%. The onset of the coral bleaching corresponded with increased seawater surface temperatures at Unguja Island. The intrusion of a cold water mass, cooling the water around Unguja Island in mid-March could be the reason for a comparatively low coral mortality on these reefs. In all areas, corals were more affected in shallow waters and Acropora was the most affected genus. Preliminary observations indicate that coral recovery has started on some reefs. However, because of the synergistic effects of various reef-degrading activities carried out on Tanzania reefs, rapid recovery will depend on effective enforcement of existing legislation that protects the reef environment and its resources. Effective management strategies guided by scientific advice could help in enhancing the recovery of degraded reefs.

INTRODUCTION

Corals harbour photosynthetically active dinoflagellates algae called zooxanthellae in their endodermal cells. The zooxanthellae provide the coral with large quantities of organic materials, especially high calorific value lipids and carbohydrates which are believed to provide most of the energy for maintenance, tissue and skeletal growth, and possibly reproduction (Veron, 1986; Brown and Ogden, 1993; Meehan and Ostrander, 1997). Furthermore, the zooxanthellae pigmentation is responsible for the colour of the coral colony. In return, the coral provides space, protection and nutrients to the zooxanthellae (Veron, 1986; Brown and Ogden 1993).
Coral bleaching refers to the loss of the zooxanthellae by the host (i.e. the coral), or the loss of photosynthetic pigments within the alga itself, which makes the coral transparent. Consequently, coral colony appears white due to the underlying skeleton (Figure 1). Some bleaching events are reversible and do not kill corals. However, extensive bleaching can cause mass mortality of corals and local extinction of coral species (Glynn and De Weerdt, 1991). The number of coral bleaching events has increased during the last two decades (D’Elia et al., 1991; Glynn, 1993; Meehan and Ostrander, 1997; Wilkinson et al., 1999).

A coral bleaching event may be evoked by various environmental factors, such as higher than normal sea temperatures (Glynn et al., 1988; Glynn, 1993; Goreau and Hayes, 1998).

Figure 1. Bleached corals in Zanzibar (Photos: M. Richmond, 1 May 1998)
higher levels of ultraviolet radiation (Gleason and Wellington, 1993), fluctuations in salinity (Holthus et al., 1989; Glyn, 1993), increased sedimentation (Stafford-Smith, 1993; Riegel and Bloomer, 1995), bacterial infection (Kushmaro et al., 1996), and various anthropogenic toxicants (Kendall et al., 1983).

Any anthropogenic or natural influence that causes mortality of corals has an impact on the well-being of coastal communities in Tanzania, because reefs provide food resources and income (Jiddawi and Muhando, 1990; Ngoile and Horril, 1993; Muhando, 1995; Johnstone et al., 1998, Muhando and Jiddawi, 1998) and protect the coastal zone (Wagner, 1998). Tourism based on coral reef activities is increasing rapidly and creates new opportunities for employment (Khatib, 1998). Many reefs are considered to be under pressure from anthropogenic as well as natural factors, both contributing negatively to the coral reef environment of Tanzania (e.g. UNEP, 1989; Ngoile and Horril, 1993; Johnstone et al., 1998).

Between March and June of 1998, a widespread coral bleaching incidence was witnessed in the western Indian Ocean with coral mortalities ranging from 0–100% on shallow reefs (see Wilkinson et al., 1999). The unprecedented mortality of Tanzanian corals constitutes an additional degrading factor for reefs, which are already under pressure. This paper presents the findings of coral reef surveys conducted from May 1998 to March 1999, during and after the bleaching period, on Tanzanian coral reefs.

MATERIALS AND METHODS

Coral reef assessments using the line-intercept transect method (English et al., 1994) were carried out before, during and after the 1998 bleaching event on five coral reefs (Chapwani, Changuu, Bawe, Chumbe and Kwale) around Unguja Island (Figure 2) in November 1997, May 1998, November 1998 and March 1999. In March 1999, using the same technique, assessments were carried out on Tutia, Mange and Juani reefs in Mafia Island, on Misali reef in Pemba and on reefs inside Mnazi Bay (Figure 2). At each site, the total length of transects (permanent and random) was more than 100m on the reef flat and reef slope. Surveys were conducted on the same sites as previous studies and results compared with data obtained before the 1998 coral bleaching event. The transects were laid parallel to the coast at depths between 2 and 15m. In addition to reef surveys, assessments were also carried out on coral fragments from six species transplanted in early March 1998, three weeks before the start of the bleaching event at Chumbe reefs. The health of coral transplants and the number surviving were recorded in May (during peak bleaching period), in September and in March 1999 (one year after the bleaching event).

In addition to field surveys, fishermen and local communities in the study areas were interviewed on reef community changes during and after the bleaching event. Fishermen were requested to give their opinion on the quantities of fish catch in the past four years and the year after the bleaching event.
Figure 2. The distribution of coral reefs in Tanzania and location of the study sites
The extent of live hard coral cover after bleaching was compared with that recorded before 1998. Some of the environmental characteristics at the study sites are shown in Table 1.

**Table 1. Some of the environmental characteristics in the study sites**

<table>
<thead>
<tr>
<th>Location</th>
<th>Reef site</th>
<th>Main characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unguja</td>
<td>Chapwani</td>
<td>Protected shallow patch reefs surrounded by sandy habitat. Dominated by <em>Porites</em> and <em>Acropora</em>. 0–7m deep.</td>
</tr>
<tr>
<td></td>
<td>Changuuu</td>
<td>Protected shallow reef. Dominated by <em>Porites</em> and <em>Acropora</em>. 0.5–12m deep.</td>
</tr>
<tr>
<td></td>
<td>Bawe</td>
<td>Shallow and patchy reef bordered by sandy habitat. Dominated by <em>Acropora</em> and <em>Porites</em>. 0.5–10m deep.</td>
</tr>
<tr>
<td></td>
<td>Chumbe</td>
<td>Dominated by <em>Acropora</em> and <em>Porites</em> to the north and <em>Acropora, Astreopora</em> and <em>Porites</em> to the south. 0–13m deep</td>
</tr>
<tr>
<td></td>
<td>Kwale</td>
<td>Coastal and shallow fringing reef dominated by <em>Acropora, Montipora</em> and <em>Porites</em>. 1–15m deep.</td>
</tr>
<tr>
<td>Pemba</td>
<td>Misali</td>
<td>Oceanic fringing reef dominated by <em>Acropora</em> and <em>Porites</em>. High coral species diversity. 1–60m deep.</td>
</tr>
<tr>
<td>Mafia</td>
<td>Juani</td>
<td>Oceanic fringing reef dominated by <em>Acropora</em> and <em>Porites</em>. 1–45m deep.</td>
</tr>
<tr>
<td></td>
<td>Tutia</td>
<td>Oceanic fringing reef adjacent to sand bank. Dominated by <em>Acropora</em>. 0.5–25m deep.</td>
</tr>
<tr>
<td></td>
<td>Mange</td>
<td>Oceanic reef adjacent to Mange sand bank. Dominated by <em>Acropora, Porites</em> and Agaricidae. 0.5–25m deep.</td>
</tr>
<tr>
<td>Mnazi Bay</td>
<td>Chamba cha</td>
<td>Fringing and small patchy reef inside Mnazi Bay. Dominated by <em>Acropora, Porites</em> and <em>Millepora</em>. 1–15m deep.</td>
</tr>
<tr>
<td></td>
<td>Chumba</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chamba cha</td>
<td>Fringing reef inside Mnazi Bay dominated by <em>Acropora</em> and <em>Porites</em>. 1–20m deep.</td>
</tr>
<tr>
<td></td>
<td>Kati</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

**Coral bleaching**

Coral bleaching occurred along the entire Tanzania coastline and results suggest that it started on Mafia Island and on the mainland coast in the first week of March 1998 (Wilkinson et al., 1999). In Unguja Island, the bleaching started in the last week of March.

The extent of coral bleaching was not uniform between study sites (Tables 2 and 3). Data collected during the peak of the bleaching event on selected reefs around Unguja Island (Table 2) indicated that the extent of coral bleaching ranged from 36% in Chapwani to 72% in Chumbe. At all the sites surveyed, corals in shallow water (especially on the reef flat) were more bleached than those in the deeper waters.
Table 2. The percentage of bleached hard (or stony) corals during bleaching period (May 1998) on surveyed reef sites around Unguja Island, Zanzibar

<table>
<thead>
<tr>
<th>Site</th>
<th>Chapwani</th>
<th>Changuu</th>
<th>Bawe</th>
<th>Chumbe</th>
<th>Kwale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Bleached</td>
<td>44.4</td>
<td>42.6</td>
<td>33.3</td>
<td>16.5</td>
<td>32.8</td>
</tr>
<tr>
<td>Partly Bleached</td>
<td>21.0</td>
<td>25.8</td>
<td>24.1</td>
<td>9.3</td>
<td>15.0</td>
</tr>
<tr>
<td>Completely Bleached</td>
<td>12.7</td>
<td>14.8</td>
<td>11.8</td>
<td>49.4</td>
<td>36.4</td>
</tr>
<tr>
<td>Partly Dead Coral</td>
<td>2.0</td>
<td>10.0</td>
<td>7.6</td>
<td>13.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Dead Coral</td>
<td>19.9</td>
<td>5.8</td>
<td>23.2</td>
<td>11.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Table 3. The percentage of hard live coral cover before and after the 1998 bleaching event on selected reef sites in Tanzania

<table>
<thead>
<tr>
<th>Reef site</th>
<th>Coral cover prior to bleaching (%)</th>
<th>Coral cover after bleaching (March 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapwani, Unguja</td>
<td>44 a</td>
<td>25 a</td>
</tr>
<tr>
<td>Changuu, Unguja</td>
<td>50 a</td>
<td>33 a</td>
</tr>
<tr>
<td>Bawe, Unguja</td>
<td>53 a</td>
<td>45 a</td>
</tr>
<tr>
<td>Chumbe, Unguja</td>
<td>52 a</td>
<td>42 a</td>
</tr>
<tr>
<td>Kwale, Unguja</td>
<td>30 a</td>
<td>15 a</td>
</tr>
<tr>
<td>Tutia, Mafia</td>
<td>80 b</td>
<td>13</td>
</tr>
<tr>
<td>Mange, Mafia</td>
<td>70 b</td>
<td>12</td>
</tr>
<tr>
<td>Juan, Mafia</td>
<td>70 b</td>
<td>11</td>
</tr>
<tr>
<td>Misali site 1, Pemba</td>
<td>74 c</td>
<td>17 d</td>
</tr>
<tr>
<td>Misali site 2, Pemba</td>
<td>57 c</td>
<td>7 d</td>
</tr>
<tr>
<td>Misali site 3, Pemba</td>
<td>–</td>
<td>20 d</td>
</tr>
<tr>
<td>Misali site 4, Pemba</td>
<td>30 c</td>
<td>5 d</td>
</tr>
<tr>
<td>Mbudya, Kunduchi</td>
<td>37 e</td>
<td>35</td>
</tr>
<tr>
<td>Bongoyo, Kunduchi</td>
<td>49 e</td>
<td>35</td>
</tr>
<tr>
<td>Chamba cha Chumba, Mnazi Bay</td>
<td>60 f</td>
<td>20</td>
</tr>
<tr>
<td>Chamba cha Kati, Mnazi Bay</td>
<td>60 f</td>
<td>20</td>
</tr>
</tbody>
</table>


Similar observations have been reported on reefs in Kenya, Seychelles and Maldives (Wilkinson et al., 1999).

The response to bleaching differed considerably among coral species. Corals in the genus Acropora bleached the most (e.g. up to 90% of Acropora were bleached on Chumbe Island reefs). Other coral genera that bleached included Echinopora, Montipora, Millepora, Pocillopora, Seriatopora, Galaxea, Astreopora and Lobophyllia. Other corals like Diploastrea and Pachyseris were little affected. The transplanted coral species at Chumbe reef responded differently to the bleaching stress; Galaxea fasicularis had a better survival rate than other species (such as Acropora humilis, A. austera and Pavona decussata (Figure 3).
Coral bleaching and mortality of this magnitude has not been reported before in Tanzania.

**Coral mortality**

Coral mortality ranging from 50–90% was recorded on different reefs along the Tanzania mainland coast, Mafia and Pemba islands. On Mafia Island reefs (Tutia, Juani and Mange reefs) the average percentage live coral cover was 12% (7% in March 1999 compared to 80% live coral cover in previous years (Horrill and Ngoile, 1991). On Misali reefs, coral cover decreased from 74 to 17% and from 57 to 7% in sites 1 and site 2 previously sampled by Horrill et al. (1994) and repeated in March 1999 using the same methodology. The coral cover at Chamba cha Chumba and Chamba cha Kati, inside Mnazi Bay, was estimated to range from 50–65% in 1997 (Guard et al., 1998). Observations at these sites in March 1999 revealed that the cover was reduced to between 15–30%. On Unguja reefs coral mortality due to bleaching was less severe. In Chumbe, Bawe and Chapwani reefs, coral cover decreased from 51.8, 53.1 and 50.1% to 42, 45 and 33% respectively (Table 3).

**Physical factors**

There is a range of factors that can cause coral bleaching. Factors that were suggested to cause bleaching in this study included a rise in seawater temperatures and rainfall as they corresponded to the bleaching event in Tanzania. On Unguja reefs for example, seawater temperature reached 30.5°C in April 1998, which is 2°C higher than in the previous year (Figure 4). During this period, Tanzania also experienced heavy rains compared to previous years (Figure 5). Although there are no data on the effects of rainfall on exposed tidal reefs or floods from rivers and streams, and underwater seepage (Mmochi et al., 1997) on coastal reefs, such effects cannot be ignored.
Figure 4. Surface seawater temperature (SST) on Unguja islands coral reefs from January 1997 to June 1999

Figure 5. The total monthly rainfall (in mm) on Unguja Island for 1997 and 1998
Source: Zanzibar Meteorological Department

The year 1998 was the warmest year since the history of recording water temperature 150 years ago with high water temperatures 3–5°C above normal being observed in many parts of the world (Wilkinson et al., 1999). High temperature stress has been implicated with widespread reef coral bleaching and mortality (Goreau and Hayes, 1994; Winters et al., 1998). If increased water temperature was the main cause of the bleaching event in Tanzania, the intrusion of a cold-water mass on Unguja reefs which occurs every year between February and March (Figure 4; Mwaipopo, 1988), could be responsible for the less severe bleaching and coral mortality observed on the Unguja reefs. This cold water mass may not have reached the mainland to cool the warm water moving northwards along the mainland coast. This phenomenon could explain why coral bleaching on the Kenyan coast (in early March) preceded that in Unguja Island coast (in late March). Some
of the reefs around Unguja (e.g. at Pange and Murogo) were unaffected by the bleaching event.

Reef recovery

Bleaching is known to weaken corals physiologically, slowing their growth (Goreau and Macfarlane, 1990) and reducing their reproductive abilities (Szmant and Gassman, 1990). Post-mortality observation showed that the dead coral structures were immediately colonised by opportunistic reef organisms such as filamentous algae. Although dead and covered with algae, the appearance of the reefs did not change much because their architectural structure remained intact. Thus many fishermen and tourists were unaware of the coral mortality. The corals that survived, as well as other organisms, such as sea anemones, clams, soft corals and collarimorpharians, regained their colour when the water cooled down.

By December 1998 (six months after the bleaching), macroalgae and coralline algae started to replace filamentous algae on the reefs around Unguja Island. While coralline algae were increasing on the dead coral in Bawe and Changuu, fleshy algae (mostly Sargassum and Turbinaria) began to dominate the reefs in the southern part of Chumbe and Kwale reefs.

The coral reef benthic cover assessments on Tutia, Juani and Mange reefs in Mafia, in Mnazi Bay and Misali in Pemba, revealed that fleshy macroalgae contributed less than 2% of benthic cover in these areas. Colonisation of dead coral structure by soft corals was more pronounced in high current areas in Mafia and Mnazi Bay.

Recovery of a degraded coral reef can be defined as the restoration of a coral assemblage to a degree that is comparable to the state before the disturbance (Pearson, 1981). Under natural conditions, recovery takes place through coral recruitment (Pearson, 1981; Carleton and Sammarco, 1987). Coral recruitment can take place through settlement of coral larvae and/or through vegetative propagation of detached coral fragments (Carleton and Sammarco, 1987; Holthus et al., 1989).

Information regarding sources and distribution patterns of coral larvae is necessary in the management of degraded reefs. It is a challenge to coral reef scientists to generate information on possible sources of coral larvae for species that have suffered high mortalities during bleaching (e.g. Acropora hyacinthus, A. cynthia and A. humilis). Isolated degraded reefs that are not on a larval supply route may take longer to recover (Pearson, 1981; Fisk and Harriott, 1990). In addition, coral recruitment is highly influenced by the suitability of the substrate (Carleton and Sammarco, 1987). Experiments on Unguja Island reefs have shown that coral settlement mainly occurs in crevices and under reef structures (Franklin et al., 1998) indicating that successful settlement and growth of corals could be influenced by the structural complexity of the reef. This implies that destructive activities (e.g. fishing), which flatten the coral reef structures, may not only enhance algal growth (Tunner, 1995; Done, 1992) but also bring about conditions that hinders successful coral settlement. In addition, reefs that
are covered by algae, other coral competitors and predators as well as those that are stressed by sedimentation or pollutants will take longer to recover (Pearson, 1981; Rogers, 1990; Done, 1992; Tunner, 1995). A repeat of the coral bleaching stresses witnessed in 1998 will certainly contribute to degrade the coral cover even further.

A general survey conducted in March 1999 indicated that there was considerable regeneration or growth of surviving corals in all the visited sites, except in Kwale and on the southern part of Chumbe reefs where fleshy algae were dominant. On Tutia and Mange reefs (in Mafia) and to a lesser extent on reefs in Mnazi Bay, surviving colonies of some coral species (e.g. *Echinopora*, *Montipora* and *Merulina*) were observed growing fast and covering the dead part of the colony as well as the dead *Acropora* branches (Figure 6). New coral recruits (less than 5cm canopy width) were scarce on most reefs that suffered high coral mortality. In Mafia and Mnazi Bay, the few recruits that were observed included *Pocillopora*, *Stylophora*, *Millepora* and encrusting *Montipora* species. There were no new recruits of *Acropora* observed in Mafia and Mnazi Bay in March 1999. Bawe and Changuu reefs showed the highest density of newly recruited coral colonies of assorted species.

On the reefs of Mafia, Mnazi Bay and Pemba, where the greatest mortality was recorded, it appears that recovery began one year later and the environment is now conducive for coral recruitment (e.g. clear water, less fleshy algae, intact reef structures, less sedimentation). Some authors (e.g. Loya, 1976) considered the recovery of coral assemblages disrupted by natural disturbances to be mainly a function of time. While this could be true, it has been demonstrated that human activities can cause a permanent shift towards algal-dominated reefs or even extinction (Glynn and De Weerdt, 1991; Done, 1992). In these situations appropriate management can enhance recruitment and shorten the recovery time (Hughes, 1994). This is especially true for the reefs of Tanzania, where destructive reef activities, such as dynamite fishing, dragnet-fishing and coral mining are still practised (Johnstone et al., 1998).

**Associated biota and fisheries**

Macro-invertebrates (sea urchins, sea cucumbers, sea stars, bivalves, gastropods and octopus) appeared unaffected by the coral bleaching. The coral eating crown-of-thorns starfish (*Acanthaster planci*) were observed in relatively low densities on Mnazi Bay as well as on Unguja Island reefs before and after the bleaching event (Guard et al., 1998; pers. observ.). Reef fish species composition changed with an increase in the number of herbivorous fish, which in turn added the total abundance of reef fish by 39% after coral mortality at Tutia reef, Mafia Island (Ohman et al., 1999).

The actual effects of coral mortality on fisheries remain unclear (Ohman, 1999). Fishermen in Mafia and Mnazi Bay claimed that there has been a slight increase in catch landed in early 1999 compared to previous years. The increased catch, according to them was a result of prevention of dynamite fishery in those areas. However, there is a chance that the warmer seawater (during bleaching) may have increased productivity.
Figure 6. Recovery and colonisation of some coral species on dead coral reef structures at Tutia Reef in Mafia Island Marine Park (Photo: C. Muhando, March 1999)

of phytoplankton and zooplankton, which in turn would result in a successful year class of fish recruitment (Pitcher and Hart, 1982) resulting in an increase in landed fish catch. This assumption, however, remains unresolved because there were no data collected on water column productivity.

CONCLUSION AND RECOMMENDATIONS

Extensive coral mortality occurred on the Tanzania coast after the bleaching event in 1998. Recent observations indicate that there are signs that coral will recover but the coral species composition will be different and a succession of species dominance may be witnessed. The recovery rates appear to be influenced by human activities on the
reefs. It is important now to prevent further human disturbance since its effects would be much more serious than in previous years, by interfering with the recovery process. The existing legislation protecting coral reefs in Tanzania must now be fully enforced. Furthermore, the importance of marine protected areas and marine environmental education programmes targeted to coral reef users need to be emphasised. Continued monitoring of affected reefs and the development of environmentally suitable fishing methods are equally necessary.

ACKNOWLEDGEMENT

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A preliminary observation of the flora and fauna of
Jozani-Pete mangrove creek, Zanzibar, Tanzania

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ABSTRACT

Mangrove forests are among the most productive ecosystems and constitute a variety of living resources which include a range of aquatic organisms and plants. In order to observe and document the living resources found in the Jozani-Pete mangrove creek, the area was surveyed between December 1997 and March 1998 (northeast monsoon). Recently, one section of the creek has become a popular tourist visiting site with the presence of the board walk initiated in 1997. No prior studies on this site had been conducted and therefore the present survey aimed at establishing baseline information on the biodiversity of the flora and fauna present in the area which could be used for comparison in future studies. Twenty 10-m\(^2\) randomly selected quadrats were observed both at low and high tides. The benthic organisms observed in the transects were collected and classified up to species level. The results indicated the presence of five mangrove species and nine other major groups of plants comprising 65 species. Nineteen families of animals comprising 76 species were also identified of which the most common included fishes, crustaceans and molluscs. Exploitation of the mangrove plants which cover 75% of the total area was also recorded from various parts especially along the lower rim of the creek. It is suggested that an in-depth study and monitoring of the flora and fauna of the area, especially along the boardwalk is required as well as educating the community on improved ways of utilisation of the resources to ensure the sustainability of the mangroves with the associated organisms.

INTRODUCTION

Mangrove forests are among the most productive ecosystems in the world and constitute a variety of living resources. They not only support the fauna and flora living in the ecosystem but are also important to neighbouring systems such as coral reefs and seagrass beds and are a major ecological, environmental and economic resource for tropical coastal countries (Shunula and Whittick, 1996). The resources include wood
for fuel and building, medicine, tannins and a variety of aquatic marine organisms such as crustaceans and fishes.

Jozani-Pete is one of the areas in Unguja Island with a mangrove ecosystem. This estuarine mangrove creek and its associated vegetation is situated in the southern district of Zanzibar, 35km from the island’s municipality. The creek is estimated to cover an area of about 4km². The creek borders a ‘boardwalk’ (Figure 1) which was constructed on its landward side and extends down to the vast opening on the seaward end. The area possess a great diversity of plants and animals which makes it attractive to tourists, the community and other visitors, hence predisposing the area to environmental misuse and possibly disturbance to the ecosystem through discard of solid wastes and uncontrolled exploitation.

As in other parts of the world the mangroves of Zanzibar are threatened by destruction intimately linked with human activities, such as logging for timber and cutting for fuelwood (Mkomwa, 1992; Shunula and Whittick, 1996; Semesi, 1998). Currently, timber from mangroves is the main source of fuel and construction poles in Zanzibar. Because of this, coral rag forests which previously occupied 40% of the land area in Zanzibar have almost been exhausted (Forest Sub-Commission of Zanzibar, 1997).

Proper conservation measures can be executed only where accurate inventories of the ecosystem are available. No systematic inventory has been made for Jozani-Pete mangrove creek to date apart from a short-term survey on the status and distribution of mangroves (Shunula, 1990). It is imperative that efforts are made to set an inventory on the elements of this fragile ecosystem. Such an inventory will contribute to the knowledge of the plants and animals found in the area and will also establish baseline information for comparison in future studies.

Figure 1. The mangrove boardwalk at the upper zone of Jozani-Pete creek
MATERIALS AND METHODS

Site description

The Jozani-Pete mangrove creek is located between 6° 15’ S and 39° 24’ E. The soils at Jozani-Pete mangrove vary from sandy beaches to fine clay or silt towards the landward side which is mostly a coral rag area. The Jozani-Pete creek receives an annual precipitation of about 800mm, in two seasons, i.e. March–June and September–November corresponding to long (Masika) and short (Vuli) rainy seasons respectively (Dubi pers. commun.).

Inventory design and methods

The data obtained in this study were collected in two phases. The first phase was conducted in December 1997 for one month and the second phase between 14 February –21 March, 1998 covering the northeast monsoon. Twenty blocks measuring approximately 10 x 10m each were randomly selected and surveyed within the 4km² perimeter, beginning on the landward side and proceeding towards seaward direction (Figure 2).

Sampling was conducted in all representative ecotypes found in the ecosystem (Table 1). In each sampling plot an inventory was made separately for all plants as well as animal species found by counting their number (sampling score) from which the percentage relative abundance was calculated. The plots were sampled during low tides and re-sampled after the subsequent high tide in a similar procedure. Each plot was therefore surveyed twice in not less than 8 hours per day. The species were recorded in their local names (where possible, a representative sample taken and preserved) and were later identified using the standard keys (e.g. Macnae and Kalk, 1981; FAO, 1985; Hutching and Saenger, 1987; Ronald and Menez, 1988; Cribb, 1996; UNESCO, 1997). The criteria for counting were based on the definitions shown in Table 2.

In addition, possible resident or migratory species (e.g. birds, fish, reptiles and other marine species) were also recorded through informal interviews and observations. The information to establish the degree of vegetation exploitation and extent of pollution by human activities was obtained through visual observation.

<table>
<thead>
<tr>
<th>Ecotype</th>
<th>Block number</th>
<th>Total number of blocks surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>8°, 15°</td>
<td>2</td>
</tr>
<tr>
<td>Mud</td>
<td>1°, 3°, 4°, 5°, 6°, 7°, 11°, 14°</td>
<td>8</td>
</tr>
<tr>
<td>Mud + water</td>
<td>9°, 13°</td>
<td>2</td>
</tr>
<tr>
<td>Mud + coral</td>
<td>2°, 3°, 4°, 12°</td>
<td>3</td>
</tr>
<tr>
<td>Mud + water + coral</td>
<td>16°, 17°</td>
<td>2</td>
</tr>
<tr>
<td>Water + sand + coral</td>
<td>18°, 19°, 20°</td>
<td>3</td>
</tr>
</tbody>
</table>

(*) = minimum exploitation; (°°) = maximum exploitation; (°) = without exploitation.
Figure 2. The Jozani-Pete mangrove creek sampling plots
RESULTS AND DISCUSSION

The flora

Seventy plant species belonging to 10 main vegetation types were observed. Appendix 1 presents data on mangroves and lower plant species. The lower plants included the algae, seagrasses, lichens, ferns, climbers and mangrove epiphytes. The percentage relative abundance of these vegetation types is represented in Table 3. Most of the plants species were found in water + sand + coral areas (Figure 3).

Algae

Red algae were the most abundant among the lower plants. However, the species diversity was recorded to be higher among green algae, with 22 different species recorded followed by red, brown, and blue-green algae with 19, 11 and 2 species recorded respectively (Table 3). Of the red algae Catenella nipae was the dominant species contributing over 10% of all the red algae. Hildenbrandia prototypus was the least common among the red algae (Appendix 1). Among the 22 species of green algae, four species (i.e. Boodlea composita, Halimeda discoides, H. macroloba and Codium geppii) were shown to constitute over 30% of all the species identified and appeared in about equal abundance (Appendix

<table>
<thead>
<tr>
<th>Table 2. Sampling scores with their respective categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling score</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. A summary of plant groups found in different ecotypes at Jozani-Pete creek, Dec 1997–March 1998 and their respective relative abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Mangroves</td>
</tr>
<tr>
<td>Seagrasses</td>
</tr>
<tr>
<td>Green algae</td>
</tr>
<tr>
<td>Brown algae</td>
</tr>
<tr>
<td>Red algae</td>
</tr>
<tr>
<td>Blue-green algae</td>
</tr>
<tr>
<td>Lichens</td>
</tr>
<tr>
<td>Ferns</td>
</tr>
<tr>
<td>Climbers</td>
</tr>
<tr>
<td>Mangrove epiphyte</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

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1). The most abundant brown algae species was *Ralfsia expansa* and the scarcest was *Cystoceris trinodis* (Appendix 1). The blue-green algae was represented by only two species.

**Seagrasses, lichens, ferns, climbers and mangrove epiphytes**

Seagrasses were represented by four main genera, i.e. *Thalassia*, *Halodule*, *Syringodium* and *Enhalus*. *Thalassia hemprichii* was the most abundant (2.05%) whereas *Enhalus acroides* was the least common. The other two were found in infrequent patches, but where found they tended to be in significant masses. The lichens, ferns, climbers and epiphytes were mainly observed in areas under the shade of mangroves. The epiphytes and lichens were each represented by two species, while only one species of climber and fern were identified.

The quantity of seagrasses and algae was substantially high at the seaward end of the creek, where they formed huge masses on areas adjacent to the mangrove stands. Due to this reason, the percentage relative abundance of the benthic flora is comparably high on the seaside parts of the creek (Figure 4).

The distribution of algae, seagrasses, ferns, lichens, epiphytes and climbers was typical for most mangrove ecotypes. The presence of red algae such as *Catella nipae*, *Bostrichia tenella* and *Caloglosa* species on permanently submerged areas and in tidal areas made this species more widespread than all other algae.

Most seagrass species are characteristically rhizomatous and are able to withstand tidal pressure of the seashore (Ronald and Menez, 1988). Their preferential habit of colonising highly saline sediments resulted in these plant species being recorded only from the plots sampled along the open shores. They are primarily used as a source of food for most fauna species including fish, crabs and molluscs.

**Mangroves**

Mangroves were the largest plant community observed. The plants grew vigorously and their canopy covered both banks of the creek. Five species were identified (i.e. *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Sonneratia alba* and *Avicennia marina*). *Rhizophora mucronata* was the most abundant. *Avicennia marina* was found to colonise
Figure 4. Percentage relative abundance of macrobenthic flora and fauna at Jozani-Pete creek, Dec. 1997–March 1998

areas somewhat far from the sea, along both banks of the creek especially in areas near the outer reach of high tides. The relatively higher abundance of *Rhizophora mucronata* concurs with the report by Shunula and Whittick (1996) on the distribution and ecology of the species in Zanzibar. Due to its stilt root system this species is known to thrive in muddy waterlogged soils.

**The fauna**

The observed fauna was categorised into eight main groups, i.e. Crustacea, Mollusca, Pisces, Reptilia, Mammalia, Nematoda, Insecta and Aves (Table 4). The difference in their occurrence on different ecotypes is presented in Figure 5. Also, there was a variation in the composition and disposition of animal species which was influenced by tidal changes. Unlike flora species, most of the fauna was observed in the middle zone of the creek.

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of species</th>
<th>% Relative abundance—low tide</th>
<th>% Relative abundance—high tide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustacea</td>
<td>12</td>
<td>16.88</td>
<td>16.44</td>
</tr>
<tr>
<td>Mollusca</td>
<td>8</td>
<td>15.85</td>
<td>9.19</td>
</tr>
<tr>
<td>Pisces</td>
<td>31</td>
<td>30.31</td>
<td>51.25</td>
</tr>
<tr>
<td>Reptilia</td>
<td>3</td>
<td>1.70</td>
<td>2.17</td>
</tr>
<tr>
<td>Aves</td>
<td>10</td>
<td>8.28</td>
<td>6.70</td>
</tr>
<tr>
<td>Nematoda</td>
<td>1</td>
<td>5.10</td>
<td>2.96</td>
</tr>
<tr>
<td>Mammalia</td>
<td>3</td>
<td>3.47</td>
<td>1.54</td>
</tr>
<tr>
<td>Insecta</td>
<td>8</td>
<td>18.36</td>
<td>9.74</td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
<td>99.95</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Crustacea, Mollusca, Pisces and Reptilia

Various groups of animals were observed during the high and low tides (Table 4 and Appendix 2). The most abundant group was Pisces. *Macolor niger* was the most abundant fish species during the low tides in areas with permanent water ponds among seagrass beds. However, during high tides the most abundant fish species were *Lethrinus nebulosus, Aulostomus chinensis, Mugil cephalus, Upeneus sulphureus, Ambassia chlorurus, Calotomus carolinus, Hipposcarus harid, Siganus canaliculatus, S. luridus* and *S. stellatus*. It was similarly reported by Beumer (1978) that the abundance of fish is relatively low during the low tide because only resident fishes, particularly juveniles and breeding groups, prefer the creek at this period for food and low salinity.

Crustaceans were represented by eight different crab, shrimp and lobster species. Among these crab species, *Sesarma guttatum* were the most abundant. The least abundant species from this group was *Eryphia smithii* (Appendix 2).

Mollusca was another dominant group in the area (Table 4). The corn-like gastropod *Terebralia palustris* were represented by nearly four in every 10 mollusc species counted. *Lithorina scabra, Lithodomus lithophagus, Natica gualterina* and *Saccostrea cuculata* were found in varied proportions, while *Loripes clausus, Dosinia haepatica* and *Codakia expansa* were the least abundant (Appendix 2).

Sea turtles and lizards represented the reptiles. However, this group contributed only a small part of the total fauna (Table 4).

Mammalia, Insecta, Aves and Nematoda

Birds and insects were also observed frequently and their abundance and distribution was independent of tidal changes (Appendix 2). The two nocturnal species of antelope: *Cephalophus adersi* and *C. montilosa* were also reported along the edges bordering the coral rag areas particularly during low tides. Results from this study show that nematodes
were represented by only a single species, *Tubulanus polymorphus*. Although Moore and Gibson (1981) identified this species only under the sediments of seagrass, there is a contrast in observation of these organisms. The results from Jozani-Pete creek show that the species has also extended deep under the mangrove roots. Perhaps nematodes use mangrove roots as a shelter against predation.

**Extent of exploitation**

Mangrove harvesting was observed to occur in some sections of the study area especially in the mud, mud + water and mud + coral ecotypes (Table 5). Exploitation of mangroves in Zanzibar has been shown to be more specific to some mangrove species especially *Ceriops tagal* (Forestry Sub-Commission of Zanzibar, 1997). At Jozani-Pete area this was also observed particularly at the lower portion of the creek, an area which is not protected under Jozani-Chwaka Bay Conservation Programme. It was observed that large areas were dotted with stumps of mangroves indicating recent harvests (Figure 6). The harvesting appeared to be haphazard and without sharply defined plots for harvesting, replanting or even natural regeneration. Only the exploitation of the flora was considered

**Table 5. Degree of exploitation on different ecotypes**

<table>
<thead>
<tr>
<th>Ecotype</th>
<th>% total study area</th>
<th>Dominant flora</th>
<th>Dominant fauna</th>
<th>Extent of exploitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water</td>
<td>10</td>
<td>Water</td>
<td>Fish</td>
<td>intact</td>
</tr>
<tr>
<td>2. Mud</td>
<td>40</td>
<td>Mangroves</td>
<td>Molluscs &amp; crabs</td>
<td>minimum</td>
</tr>
<tr>
<td>3. Mud+water</td>
<td>10</td>
<td>Mangrove/algae</td>
<td>Molluscs &amp; crabs</td>
<td>minimum</td>
</tr>
<tr>
<td>4. Mud+coral</td>
<td>15</td>
<td>Mangrove/algae</td>
<td>Molluscs &amp; crabs</td>
<td>maximum</td>
</tr>
<tr>
<td>5. Mud+water+coral</td>
<td>10</td>
<td>Mangrove/algae</td>
<td>Fish</td>
<td>minimum</td>
</tr>
<tr>
<td>6. Water+sand+coral</td>
<td>15</td>
<td>Algae</td>
<td>Fish/molluscs/crabs</td>
<td>intact</td>
</tr>
</tbody>
</table>

Note: minimum = up to 50% harvested; maximum = >50% harvested; intact = no exploitation.

![Figure 6. Uncontrolled mangrove cutting at the lower rim of the Jozani-Pete Mangrove Creek Dec 1997–March 1998](image)

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in this study and it was established from the informal interviews and observations that mangroves were being cut for fuelwood and building.

CONCLUSION

Global mangrove ecosystems have shown some unique composition in their flora and fauna inventories. It was observed that mangroves and their associated organisms prefer some common physio-chemical environments and ecotypes regardless of the differences in their geographical location. Many authors and specialists in this field (e.g. Mkomwa, 1992; Semesi, 1992; Shunula and Whittick, 1996) have repeatedly advocated the importance of mangrove ecosystem conservation, recognising its fragility and productivity. Proper documentation and protection of this natural resource is therefore crucial in order to ensure sustainability.

The current situation at Jozani-Pete creek is not yet alarming. However, it appears that as pressure for fuelwood and timber in other areas on the island is mounting, there is an urgent need for concerted conservation measures to be taken in order to secure the well-being of this ecosystem.

The fauna found at the creek is varied and offers unique opportunities for controlled exploitation. Villagers residing in the neighbourhood could be educated in sustainable measures of exploiting this resource.

The results obtained from this study are not sufficiently comprehensive. However, they do provide baseline information on which further studies on biodiversity and conservation strategies might be based. There is a need for in-depth study of the flora and fauna and their interactions in mangrove ecosystems. Also, practices directed at utilisation of mangrove resources should go hand in hand with conservation strategies. Utilisation should be monitored in such a way that consumption does not exceed production. For proper conservation, the community residing in the neighbourhood of the creek should be involved in the conservation and utilisation of the mangroves.

REFERENCES

Appendix 1. Flora species found at the Jozani-Pete mangrove creek, Zanzibar, December 1997–March 1998

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<td>42</td>
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<td><em>Siganus luridus</em></td>
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<tr>
<td>44</td>
<td><em>Siganus stellatus</em></td>
<td>Pisces</td>
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</tr>
</tbody>
</table>

*Continued next page*
### Appendix 2. Continued

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Scientific name</th>
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<th>Low tide</th>
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<td></td>
<td>Sampling score</td>
<td>% Rel. abundance</td>
<td>Sampling score</td>
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<td><em>Platia orbiculatus</em></td>
<td>Pisces</td>
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<td>1.36</td>
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<td><em>Zebrasoma veliferum</em></td>
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<tr>
<td>53</td>
<td><em>Eretmochelys imbricata</em></td>
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</tr>
<tr>
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<td><em>Loriculus curvirostra</em></td>
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<td><em>Ciconia ciconia</em></td>
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<tr>
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<td><em>Puffinus puffinus</em></td>
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<td><em>Zosterops lutea</em></td>
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<td>1.02</td>
</tr>
<tr>
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<td><em>Ficedula hypoleuca</em></td>
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<td>1.02</td>
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<td><em>Eopsaltria pulverulentia</em></td>
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<td><em>Cephalophus montilosa</em></td>
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</tr>
<tr>
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<td><em>Procolobus kirkii</em></td>
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<td><em>Apis mellifera</em></td>
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<tr>
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<td><em>Captotettis masticatus</em></td>
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<td><em>Colobopsis spp.</em></td>
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<td><em>Aedes spp.</em></td>
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</tr>
<tr>
<td>75</td>
<td><em>Anopheles spp.</em></td>
<td>Insecta</td>
<td>30</td>
<td>2.04</td>
</tr>
<tr>
<td>76</td>
<td><em>Culicoides spp.</em></td>
<td>Insecta</td>
<td>15</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Total: 1470 100.00 2536 100.00
The seagrass and associated macroalgae at selected beaches along Dar es Salaam coast

B.R. Lugendo¹ Y.D. Mgaya¹ and A.K. Semesi²

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ABSTRACT

Intertidal seagrasses and macroalgae were studied at a sewage-polluted beach (Ocean Road) and a control site at Kunduchi beach, with a view to assessing the effect of sewage discharge on macrophyte species composition, abundance and above-ground biomass. A total of six species of seagrasses were recorded at Ocean Road of which two, *Thalassia hemprichii* and *Cymodocea rotundata* were the most abundant. Eight species of seagrasses were recorded at Kunduchi. Two species, *Syringodium isoetifolium* and *Thalassodendron ciliatum* were dominant in areas with strong oceanic influence. *Halodule wrightii* and *Halophila ovalis* were widely distributed in the two study areas. The mean biomass of seagrasses between Ocean Road and Kunduchi beaches was not significantly different (z = 4.053; p = 0.001; d.f. = 54). A total of 25 and 24 macroalgae species were recorded at Ocean Road and Kunduchi beaches, respectively. The total biomass of macroalgae was higher at Ocean Road than at Kunduchi (t = 4.838; p > 0.001). While the biomass of brown macroalgae was higher at Kunduchi (t = 2.115; p = 0.039), that of red algae was similar at both sites (t = 1.986; p = 0.052). Of the 11 epiphytic species of macroalgae recorded on *T. ciliatum* at Kunduchi area, 73% were red algae, 18% green algae and 9% brown algae. The dominant species on this beach was the brown alga *Cystoseira myrica*. It was concluded that elevated levels of ammonium at Ocean Road is a likely cause of the observed higher biomass of green macroalgae at this site.

INTRODUCTION

Seagrasses are marine angiosperms that are adapted to live permanently submerged in seawater. Worldwide, there are about 58 known species (Bandeira, 1995; Richmond, 1997) and about 12 of them are found in the East African region (Phillips and Menez, 1988). In this region, the main seagrass beds are located in between the coral reefs, mangal ecosystems, and on reef flats (Uku, 1996).
Seagrasses occupy a wide range of substrates (mostly soft sediments) exploiting nutrients found within the sediment. Apart from stabilising the substratum, their most notable role is that they provide breeding, nursery and feeding areas for many invertebrates and vertebrate species, many of which are of commercial and recreational importance (Fortes, 1988; Walker, 1989). As a result both artisanal and commercial fishery activities in several parts of the world are carried out in seagrass beds (Bandeira, 1995). A large proportion of their biomass goes into the detritus food chain (Walker, 1989). In some parts of the world (such as Philippines and Kenya), seagrasses are also used directly for making paper, green manure and fodder (Thayer et al., 1975; Coppejans et al., 1992; Bandeira, 1995).

Worldwide, seagrasses are subjected to stresses resulting from human activities, among them is sewage disposal. The use of coastal areas as dumping ground for domestic sewage and industrial discharge poses a threat to this ecosystem. Apart from organics, chlorine and some heavy metals, this discharge contains inorganic nutrients, in particular nitrogen and phosphate (Lobban and Harrison, 1994). In small volumes and with adequate diffusing pipes, it is difficult to detect any long-term effect of nutrient on the seagrass communities. However, in large volumes and in semi-enclosed embayments, high nutrient levels can be destructive.

Like in many tropical regions, the Dar es Salaam coast has well developed seagrass communities (Semesi and Shushu, 1988). One of its beaches, Ocean Road area receives domestic sewage through a pipe that drains the city centre. This pipe discharges onto the mud flats that are exposed at low tides from several leaks in the pipe. Therefore the intertidal seagrasses of the area are prone to the effects of sewage because they lie close to the outfall pipe. Another area, Kunduchi, located about 25km north of Ocean Road area, receives no direct sewage discharge.

The present study set out to investigate the effect of elevated nutrient levels resulting from sewage discharge on the composition and biomass of macroflora. To achieve this objective, Ocean Road was selected as the test site and Kunduchi as the control site.

MATERIALS AND METHODS

Study sites
The study sites were Ocean Road and Kunduchi along Dar es Salaam coast. Ocean Road is on the northern side of the Dar es Salaam Harbour (Figure 1), a short distance from the entrance to the harbour. This beach extends northwards to the mouth of Msimbazi creek. To the south, the beach is protected from open sea by the Kigamboni headland as a result of change of the coastal alignment across the harbour, and Inner and Outer Makatume islands. The substrate is diverse, but mainly consists of coarse/medium sand; at other places, however, one sinks knee-deep in the mud.
The intertidal mudflat of Kunduchi is located off Silver Sands Hotel (about 1km north of Kunduchi Marine Biological Station, Figure 1). During the rainy season the area receives discharges from Tegeta River and the water becomes extremely turbid. This condition may prevail throughout the rainy period, but as the flow decreases the creek is sealed off for most of the year by the shifting sand. The sediment consists of

Figure 1. A map of Dar es Salaam coast showing study sites
fine sand except during the rainy season when fine mud persists. Well developed, mixed seagrass beds occur at both sites.

**Sampling stations**

Three transects were established at each study site. The transects were perpendicular to the shore and extended seaward from the upper seagrass zone to 100m, and were 150m apart. At Ocean Road area the three transects were established northwards from the sewage outfall pipe while at Kuduchi area, the transects covered the area in front of Silver Sands Hotel, to the area adjacent to Rungwe Oceanic Hotel.

Sampling was undertaken monthly for over one year starting from August 1996 to July 1997 (except June 1997). In most cases, sampling was carried out during the low spring tides as this was when the seagrass beds were exposed and easily accessible.

**Seagrass and algal species composition, biomass and abundance**

A taxonomic survey of seagrasses and associated algae was undertaken along the line transects. A quadrat measuring 0.0625m² was placed at intervals of 10, 30, 50, 70, and 90m from the upper seagrass limit in the intertidal area towards the sublittoral zone. Identification of floral species was undertaken with the help of botanical keys by Isaac and Isaac (1968), den Hartog (1970), Jaasund (1976), Phillips and Menez (1988), Moorjani and Simpson (1988).

To determine biomass, samples of seagrasses and the associated macroalgae were cropped from the quadrat and sealed in numbered bags and taken to the laboratory. The seagrass samples were divided into leaves and rhizomes. The leaves and the macroalgae were oven-dried at 65°C to a constant weight. This provided the estimate of the above-ground and macroalgae biomasses.

The abundance was expressed as a percentage, calculated as the number of quadrats in which a particular species was observed divided by the total number of quadrats sampled in the area over the study period and multiplied by one hundred.

**Nutrient analysis**

Seawater samples were collected in 100ml plastic bottles washed with 10% hydrochloric acid. The samples were filtered through GF/C microfibre filters and then frozen at -20°C to avoid metabolism by microorganisms (Uku, 1996). The inorganic nitrate, ammonium and phosphate were determined using methods described by Parsons et al. (1989). All the reagents used were of the analytical grade.

To determine pore water nutrient, a corer of 6.8cm diameter and 10cm length was used to sample the sediment to a depth of 5cm. Samples were taken to the laboratory where plant parts, living macrofauna, shells and large stones were removed. Pore water was subsequently extracted by suction using a vacuum pump and followed by filtration using Whatman GF/C filters. The filtrate obtained was analysed for ammonium and phosphates as detailed in Parsons et al. (1989).
Temperature, salinity, pH, DO and BOD

During each field visit, the surface water temperature, salinity and pH were recorded at each sampling point. Dissolved oxygen (DO) and biological oxygen demand (BOD) were determined by the Winkler method (Parsons et al., 1989).

Data collected were analysed statistically using the following tests: t-test or its non-parametric equivalent, Mann-Whitney U-test (Zar, 1984) and Friedman’s non-parametric randomised block ANOVA. All statistical inferences were based on a significance level of $\alpha = 0.05$.

The $z$ symbol was used for Mann-Whitney test instead of $U$ symbol because the d.f. exceeded 40.

RESULTS

Species composition, abundance and biomass of seagrasses

The families Potamogetonaceae and Hydrocharitaceae were well represented at both sites. All seven seagrass genera known for the tropical Indo-West Pacific (den Hartog, 1970) were represented among the 9 species identified. Table 1 shows the seagrass species and their overall abundance recorded during the study. A total of six species of seagrasses were recorded at Ocean Road of which Thalassia hemprichii and Cymodocea rotundata were the most abundant. Eight species were recorded at Kunduchi, with two, Syringodium isoetifolium and Thalassodendron ciliatum, being dominant.

<table>
<thead>
<tr>
<th>Table 1. Seagrass species composition and abundance at Ocean Road and Kunduchi areas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Thalassodendron ciliatum</td>
</tr>
<tr>
<td>Cymodocea serrulata</td>
</tr>
<tr>
<td>Cymodocea rotundata</td>
</tr>
<tr>
<td>Syringodium isoetifolium</td>
</tr>
<tr>
<td>Enhalus acoroides</td>
</tr>
<tr>
<td>Thalassia hemprichii</td>
</tr>
<tr>
<td>Halophila ovalis</td>
</tr>
<tr>
<td>Halodule wrightii</td>
</tr>
<tr>
<td>Halodule uninervis</td>
</tr>
<tr>
<td>Total number of species</td>
</tr>
</tbody>
</table>

- : absent in all quadrats sampled per transect throughout the year.
1+ : present in 1–9% of all of the quadrats sampled per transect during the year.
2+ : present in 10–19% of all of the quadrats sampled per transect during the year.
3+ : present in 20–29% of all of the quadrats sampled per transect during the year.
4+ : present in 30–39% of all of the quadrats sampled per transect during the year.
5+ : present in 40–49% of all of the quadrats sampled per transect during the year.
6+ : present in 50% and over for all quadrats sampled per transect during the year.
The highest mean biomass value (± SD) recorded was 135.29 ± 37.29g dw/m² and the lowest was 0.25 ± 0.44g dw/m². Seasonal fluctuation in biomass was not significant (z = 4.08; p > 0.05; z = 4.0483; p < 0.05 at Ocean Road and Kunduchi, respectively). Also, a Mann-Whitney U test showed that mean biomass at the two study areas was not significantly different (z = 4.053; p > 0.05). Friedman’s randomised block ANOVA revealed that the distribution of seagrass across these beaches was significantly different (χ² = 22.036; d.f. = 4, p = 0.000; χ² = 38.594; d.f. = 4; p < 0.001) for Ocean Road and Kunduchi areas respectively. This test was followed by Dunn’s multiple comparison test using InStat statistical program (Table 2).

Table 2. Results of Dunn’s multiple comparisons test for difference in biomass of seagrass between pairs of stations (For each station, n=11)

<table>
<thead>
<tr>
<th>Ocean Road area</th>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank-sum</td>
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<td>13</td>
<td>30</td>
<td>37</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td>Kunduchi area</td>
<td>Station</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Rank-sum</td>
<td></td>
<td>11.5</td>
<td>26.5</td>
<td>31</td>
<td>41</td>
<td>55</td>
</tr>
</tbody>
</table>

Species composition, abundance and biomass of macroalgae
Table 3 shows the species of macroalgae and their overall abundance at Ocean Road and Kunduchi. A total of 25 and 24 species were recorded at Ocean Road and Kunduchi, respectively. Of the 24 species recorded at Kunduchi, 11 occurred as epiphytes on Thalassodendron ciliatun (Table 4). Ulva reticulata, Chaetomorpha indica and Enteromorpha ramulosa occurred in all transects at Ocean Road with Ulva reticulata being the most abundant. The biomass of green algae at Ocean Road was significantly higher than at Kunduchi (t = 4.8380; p = 0.001; d.f. = 54).

Conversely, the biomass of brown macroalgae at Kunduchi was significantly higher than at Ocean Road (t = 2.1152; p = 0.039; d.f. = 54). However, the biomass of red algae at the two areas was not significantly different (t = 1.9862; p = 0.052; d.f. = 54). Red algae were the most represented group (19 species) followed by green algae (9 species). Brown algae were the least represented. Generally, the macroalgal biomass was relatively lower than seagrass biomass.

Physico-chemical parameters
Data on some meteorological and other physico-chemical parameters are presented in Figure 2. The water temperature ranged from 24 to 35°C, salinity from 16 to 37‰, pH from 6.9 to 8.6, dissolved oxygen from 2.42 to 3.86mg/l and BOD from 0.1 to 3.1mg/l.
Table 3. Species composition and abundance of macroalgae at Ocean Road and Kunduchi

<table>
<thead>
<tr>
<th>Species</th>
<th>Ocean Road transects</th>
<th>Kunduchi transects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR1</td>
<td>OR2</td>
</tr>
<tr>
<td>Green macroalgae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caulerpa serrulatoïdes (Gmelin) Howe</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chaetomorpha crassa (Ag.) Kütz.</td>
<td>1+</td>
<td>-</td>
</tr>
<tr>
<td>Chaetomorpha indica Kütz.</td>
<td>1+</td>
<td>1+</td>
</tr>
<tr>
<td>Cladophora fascicularis (Mert.) Kützing</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Enteromorpha ramulosa (J.E. Smith) Hooker</td>
<td>2+</td>
<td>1+</td>
</tr>
<tr>
<td>Ulva fasciata Delile</td>
<td>1+</td>
<td>1+</td>
</tr>
<tr>
<td>Ulva reticulata Forskål</td>
<td>-</td>
<td>2+</td>
</tr>
<tr>
<td>Udotea palmetta Descaine</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Udotea orientalis Weber van Bosse</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Brown macroalgae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cystoseira myrica (Gmelin) C. Agardh</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dictyota divaricata Lamouroux</td>
<td>1+</td>
<td>-</td>
</tr>
<tr>
<td>Padina gymnospora (Kütz.) Vickers</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stoechospermum marginatum (Ag.) Kütz.</td>
<td>1+</td>
<td>-</td>
</tr>
<tr>
<td>Spatoglossum aspernum J. Ag.</td>
<td>1+</td>
<td>-</td>
</tr>
<tr>
<td>Sargassum torvum J. Agardh</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Red macroalgae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrosorium amphiroae Jaasund</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Amphiroa fragilisima (L.) Lamouroux</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ceramium codii (Richards.) Feldmann-Mazoyer</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gelidiella acerosa (Forsk.) Feldmann et Hamel</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gelidiopsis variabilis (Grev.) Schmitz</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gracilaria corticata J. Agardh</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Gracilaria crassa Harvey</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gracilaria millardetii J. Agardh</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gracilaria sp.</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Halymenia venusta Börgeesen</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Hypnea cornuta (Lamour.) J. Agardh</td>
<td>1+</td>
<td>1+</td>
</tr>
<tr>
<td>Hypnea hamulosa (Turn.) Montagne</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hypnea musciformis (Wulfen) Lamouroux</td>
<td>1+</td>
<td>1+</td>
</tr>
<tr>
<td>Hypnea ridiflora J. Agardh</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jania adherens Lamouroux</td>
<td>1+</td>
<td>1+</td>
</tr>
<tr>
<td>Sarconema scinaioides Börgeesen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sarconema filliforme (Sonder) Kylin sensu</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Papenfuss and Edelstein</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soliera robusta (Grev.) Kylin</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wrangelia bicuspidata Börgeesen</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*: absent in all quadrats sampled per transect during the year.
1+: present in 1–9% of all the quadrats sampled per transect during the year.
2+: present in 10–19% of all the quadrats sampled per transect during the year.
3+: present in 20–29% of all the quadrats sampled per transect during the year.
OR1, OR2, OR3: transects 1, 2, 3 at Ocean Road; K1, K2, K3: transects 1, 2, 3 at Kunduchi.
Table 4. Epiphytic macroalgae found on the seagrass *Thalassodendron ciliatum* at Kunduchi area. R = red alga; B = brown alga; G = green alga

<table>
<thead>
<tr>
<th>Species</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaetomorpha indica (Ag.) Kütz.</td>
<td>G</td>
</tr>
<tr>
<td>Ulva fasciata Dellele</td>
<td>G</td>
</tr>
<tr>
<td>Padina gymnospora (Kütz.) Vickers</td>
<td>B</td>
</tr>
<tr>
<td>Wrangella bicuspidata Borgesen</td>
<td>R</td>
</tr>
<tr>
<td>Gelidiella acerosa (Forsk.) Feldmann et Hamel</td>
<td>R</td>
</tr>
<tr>
<td>Gelidiopsis sp.</td>
<td>R</td>
</tr>
<tr>
<td>Herposiphonia insidiosa (Grev.) Falkenberg</td>
<td>R</td>
</tr>
<tr>
<td>Hypnea musciformis (Wulfen) Lamouroux</td>
<td>R</td>
</tr>
<tr>
<td>Ceramium sp.</td>
<td>R</td>
</tr>
<tr>
<td>Gracilaria corticata J. Agardh</td>
<td>R</td>
</tr>
<tr>
<td>Jania adherens Lamouroux</td>
<td>R</td>
</tr>
</tbody>
</table>

**Nutrients in the water column**

The highest mean concentration of nitrate (±SD) recorded was $2.41 \pm 0.14 \mu M$ and the lowest was $0.18 \pm 0.02 \mu M$ at Ocean Road (Figure 3). At Kunduchi, mean nitrate concentration was $2.41 \mu M$ and the lowest was $0.22 \mu M$ (Figure 3). At both sites, the nitrate levels during the rainy season were significantly higher than during the dry season (Ocean Road: $t = 4.5794$; $p = 0.0004$; d.f. = 14; Kunduchi: $t = 3.6222$; $p = 0.0028$; d.f. = 14). The levels of water nitrate were higher at Kunduchi than at Ocean Road ($t = 4.9099$; $p = 2.5817 \times 10^{-5}$; d.f. = 29).

At Ocean Road, the highest mean level of ammonium recorded was $8.9 \mu M$ (Figure 3). The difference in ammonium levels between the dry and rainy seasons was not significant ($t = 1.8771$; $p = 0.0815$; d.f. = 14). The highest mean level of ammonium at Kunduchi was $2.01 \mu M$ (Figure 3). The levels recorded in the rainy season were significantly higher than in the dry season ($t = 2.5251$; $p = 0.0243$; d.f. = 14). Overall, the ammonium levels in the water column at Ocean Road were significantly higher than at Kunduchi ($t = 3.997$; $p = 0.0002$; d.f. = 29).

At Ocean Road area the highest phosphate level (±SD) recorded was $1.47 \pm 1.24 \mu M$ (Figure 3). The levels of water column phosphate during the rainy and dry season was not significantly different ($t = 0.9199$; $p = 0.3732$; d.f. = 14). At Kunduchi, the highest recorded mean value (±SD) was $0.87 \pm 0.04 \mu M$ (Figure 3). The levels of water column phosphate during the rainy period were significantly higher than those of the dry period ($t = 7.7148$; $p = 0.001$; d.f. = 14). The water column phosphate levels at the two study areas was not significantly different ($t = 1.2186$; $p = 0.2328$; d.f. = 29).

**Nutrients in the pore water**

At Ocean Road, the mean pore water ammonium peaked in March when a mean of $77.01 \mu M$ was recorded (Figure 3). There was no significant difference between the pore water ammonium recorded in the rainy period and in the dry period ($t = 1.2798$; $p = 0.2214$; d.f. = 14). At Kunduchi area, the highest mean concentration recorded
Figure 2. Variations in (a) rainfall, (b) air temperature, (c) water temperature at Ocean Road, (d) water temperature at Kunduchi, (e) salinity at Ocean Road, (f) salinity at Kunduchi, (g) water pH at Ocean Road, (h) water pH at Kunduchi during the sampling period. The distances shown in 2c apply to 2d through 2h.

was 50.84μM (Figure 3). The ammonium recorded in the pore waters of Ocean Road was significantly higher than that of Kunduchi ($t = 2.9666$; $p = 0.0029$; d.f. = 29). The seasonal variations were not statistically significant ($t = 2.1174$; $p = 0.0523$; d.f. = 14). The levels of pore water ammonium were significantly higher than those of the water column at both study areas (Ocean Road: $t = 5.7088$; $p = 3.55 \times 10^{-6}$; d.f. = 29; Kunduchi: $t = 5.4621$; $p = 7.03 \times 10^{-6}$; d.f. = 29).
Figure 3. Variations in (a) water column nitrate at Ocean Road, (b) water column nitrate at Kunduchi, (c) water column ammonium at Ocean Road, (d) water column ammonium at Kunduchi, (e) pore water ammonium at Ocean Road, (f) pore water ammonium at Kunduchi, (g) water column phosphate at Ocean Road, (h) water column phosphate at Kunduchi, (i) pore water phosphate at Ocean Road, (j) pore water phosphate at Kunduchi.
A highest mean pore water phosphate concentration (±SD) of 22.16 ± 7.24µM and 4.92 ± 0.21µM was recorded at Ocean Road and Kunduchi, respectively (Figure 3). The levels of pore water phosphate recorded in the rainy period were significantly higher than during the dry season (t = 4.6951; p = 0.0003; d.f. = 14). The levels of pore water phosphate at Ocean Road area were significantly higher than at Kunduchi (t = 4.9076; p = 0.000; d.f. = 29). Furthermore, the levels of pore water phosphate were significantly higher than those of the water column at both sites (Ocean Road: t = 5.9651; p = 0.001; d.f. = 29; Kunduchi: t = 5.9759; p = 0.001; d.f. = 29).

DISCUSSION

Seagrass species composition, abundance and distribution

The fluctuations in environmental factors at different zones of the intertidal area are responsible for the distribution of some species encountered during this study. For example, seagrass species like H. uninervis which is tolerant to fluctuations in salinity (den Hartog, 1970) was found at the beach end of Kunduchi area where salinity was normal during dry season, and dropped in abundance during rainy season due to the influence of the Tegeta River.

The seagrass distribution at both study areas is more or less similar to that described by den Hartog (1977). The smaller species, i.e. the parvozosterids (Halodule spp.) and halophilids (Halophila spp.) inhabit the upper levels of the beach. The coarser magnozosterids (Thalassia sp. and Cymodocea spp.) and amphibolids (Thalassodendron sp.) were found in the seaward sections of the transects.

Thalassia hemprichii and Cymodocea rotundata were the dominant seagrass species at Ocean Road area. At Kunduchi area, Thalassodendron ciliatum, Syringodium isoetifolium and Halodule uninervis were the dominant species. Halodule wrightii dominated the seagrass community only in limited areas where physical conditions precluded dense stands of T. hemprichii and C. rotundata. In a similar work in Florida, Lapointe et al. (1994) concluded that Thalassia testudinum is an indicator of oligotrophic conditions while Halodule wrightii is an indicator of eutrophic conditions. The occurrence of several species of seagrasses at Ocean Road and the lack of dominance of H. wrightii might indicate that Ocean Road area has not yet experienced the shift in seagrass species that is typical of eutrophic areas. It might also indicate that H. wrightii does not always dominate eutrophic areas as reported by Lapointe et al. (1994). Halodule wrightii was dominant in the shores of Kunduchi. However, its association with other species points to the influence of other physico-chemical factors other than eutrophication.

Although Ocean Road receives sewage discharge, seagrasses grow well in the intertidal area indicating that the concentrations of nutrients have not yet reached limiting levels that would lead to dominance of macroscopic algae and phytoplankton. This could be attributable to high flushing rates of sewage in the area such that few, if any, nutrients were reaching the intertidal area.
Seagrass biomass

The seagrass community at Ocean Road occurs in patches. As a result there is no uniform pattern in biomass distribution among the transects. This patchy distribution is either due to deterioration of a once-continuous meadow, or to an environmental limitation. Physical removal of seagrass by researchers, local fishermen in search of baits and/or some edible mollusc and octopus (pers. observ.) can lead to substantial damage.

The seaward increase in biomass observed at Kunduchi transects can be attributed to the size distribution of the species (Uku et al., 1996). The smaller species like Halophila spp. and Halodule spp. contributed to the low biomass levels at the beach end while the larger species like Syringodium isoetifolium and Thalassodendron ciliatum contributed to the higher biomass seaward (Uku, 1996).

Biomass and productivity of seagrasses exhibit seasonal variation, which has been attributed to periodical fluctuation of environmental factors such as light, nutrient availability, temperature, salinity, herbivory and hydrological conditions. However, there were no variations in biomass with seasons in either study area. Being within the tropics, the comparatively uniform temperature and day length allow rather constant growth throughout the year and consequently a uniform biomass throughout the year (Stapel, 1997).

Macroalgae species composition, abundance, distribution and biomass

The higher biomass of green macroalgae observed at Ocean Road compared to Kunduchi area could be explained by the algae’s response to high levels of nitrogen in the water column. Although the nitrate level in the water column at Ocean Road was lower than at Kunduchi area, there was a significantly higher level of ammonium in the water column at Ocean Road. Usually ammonium is the preferred form of nitrogen and is generally taken up in preference to all other nitrogen sources (Lobban and Harrison, 1994). Response of seaweeds to high nutrient levels is well documented (Sawyer, 1965; Tewari, 1972; Waite and Mitchell, 1972; Harlin and Thorne-Miller, 1981; Lobban and Harrison, 1994). Harlin and Thorne-Miller (1981) observed a bloom of Enteromorpha plumosa and Ulva lactuca in response to nitrate and ammonium enrichment.

The epiphytic macroalgae found in this study showed an exceptional preference for the stems of Thalassodendron ciliatum. The rough surface of the stems renders them suitable for the settlement of algal spores and, unlike leaves which are shed off easily, the longevity of the stems provides an opportunity for the algae to grow (Semesi, 1988; Uku et al., 1996). Similar observation of high epiphytic algal biomass on the stems of T. ciliatum was reported by Uku et al. (1996) in Diani and Galu beaches, Kenya. They suggested that the high epiphytic load recorded at these beaches was due to the availability of appropriate substratum rather than the effect of eutrophication. This could explain the situation prevailing at Kunduchi area, where the highest epiphytic macroalgal biomass was recorded in the seaward end where T. ciliatum occurred.
Nutrients

In this study, the floral communities appear unable to remove all nutrients from the water column, as significant measurable levels were detectable. This suggests that there are surplus nutrients not being utilised by the communities. This indicates that the significant nutrient levels recorded in the study areas must have an external source other than the ocean itself. The influence of sewage at Ocean Road area and seasonal stream inflow at Kunduchi area are possibly the major sources of nutrients. There could also be ground water input into the area. The activity of nitrogen fixing cyanobacteria present in the waters could also be of importance (Bryceson, 1977; McClanahan, 1988; Lyimo, 1995).

The significant high pore water nutrient levels recorded under this study compared to those of the water column conforms with observation made by other authors (Stapel, 1997; Harlin and Thorne-Miller, 1981), and seem to confirm that sediment pore water nutrients are the primary source of nutrient for seagrass growth (Johnson and Johnstone, 1995; Fourquean et al., 1992). Uptake by phytoplankton, macroalgae and vascular plants (Uku, 1996; Stapel, 1997) could explain the low nutrient resource in the water column compared to the much higher resources in the pore water where macroalgae and phytoplankton have no direct access.

The seagrass communities under study appear to cope well with the elevated levels of nutrients, but it is unclear as to whether it would continue to tolerate further elevation of dissolved nutrient levels. Given the relative high nutrient levels observed and involvement of macroalgae biomass, it may be that the seagrass community of Ocean Road area are presently at their upper threshold for nutrient loading. In the long term, such stress may cause severe deleterious effects (Tomasko and Lapointe, 1991; Shepherd et al., 1989).

In conclusion, this study is in agreement with a previous study by Semesi and Shushu (1988), which concluded that the seagrass beds of Dar es Salaam consist of mixed seagrass species. Furthermore, the nutrient levels have not yet reached those of intense eutrophication which would result in monospecific seagrass beds, as reported elsewhere (Stapel, 1997). However, the abundance of green macroalgal species at Ocean Road points to elevated levels of nutrients in the area.

REFERENCES


A comparative study of the ecology of four sandy/muddy shores in the Dar es Salaam area

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ABSTRACT

An ecological study was conducted on four shores in the Dar es Salaam area, Kunduchi, Ocean Road, Mjimwema/Kendwa and Mtoni. The following were determined monthly for a period of one year: particle size, organic matter content, and percent pore water of the substrate; salinity; dissolved oxygen concentration in tidal pool water; and density, biomass and species diversity of benthic macrofauna.

There was a very significant difference in density (randomised block analysis of variance, $F = 22.751, p = 3.609 \times 10^{-6}$), and biomass (Friedman's test, Chi-square $= 23.900, p = 2.576 \times 10^{-5}$) of the four shores. Kunduchi and Ocean Road were similar in all the abiotic factors measured. Both shores had moderate species diversity, but low density and biomass of macrofauna. Besides being under environmental stress due to desiccation, these shores have been exposed to anthropogenic impacts due to excessive movement of boats and people, destructive fishing methods and pollution.

In comparison with Kunduchi and Ocean Road, Mjimwema/Kendwa had higher percent pore water, lower organic matter content, but approximately the same dissolved oxygen and salinity levels. Due to the physical contours of the surrounding area, this shore never completely drains and there are relatively few anthropogenic effects. Compared to the other three shores, Mjimwema/Kendwa had the highest biomass and species diversity of macrofauna. It also had high density.

At Mtoni, the substrate was determined to be very fine silt, poorly sorted, with very low percent pore water and a high build up of organic matter. Since it is in an estuary, salinity was lower than on the other shores and showed the greatest drop during the rainy season. Compared to the other three shores, Mtoni had the lowest species diversity, lowest biomass, yet highest density. This was due to the high density of two species of very small organisms that seem to be adapted to that stressful environment, i.e. Arcuatula arcuata and Modiolus sp.

All shores showed the lowest biomass levels in their upper parts where crabs dominated. In this zone, Dotilla fenestrata was dominant on
all shores along with either *Ocypode* spp. (Kunduchi, Ocean Road and Mjimwema) or *Uca* spp. (Mtoni). At Kunduchi and Ocean Road the midshore was dominated by a variety of polychaetes, sipunculids, bivalves and crabs, while holothurians dominated the lower shore. At Mjimwema/Kendwa, the midshore was dominated by a variety of gastropods, bivalves, sponges, holothurians, sea urchins and brittle stars.

**INTRODUCTION**

Abiotic factors control the activities of organisms. The organisms, in turn, influence the abiotic and biotic environments, thus showing the difficulty in compartmentalising ecological factors. Thus, in this study, both biotic and abiotic factors have been investigated. The biotic and abiotic factors which govern species composition and community structure in intertidal habitats are generally similar at all latitudes and any differences are usually a matter of degree (e.g. competition, temperature, grain size, rainfall and beach slope) (Vargas, 1988). Of course, in many areas, anthropogenic factors also have significant impact on marine ecosystems. The intertidal zone is often a major impact area for human activities.

Marine ecological studies aim at understanding marine ecosystems as working processes and at determining the specific interactions that occur among abiotic and biotic factors at particular latitudes or in particular geographical areas. This study was an attempt to look at the Dar es Salaam sandy/muddy shores as a habitat and as an ecological unit. In a larger sense, it is also a step towards understanding the ecology of tropical Indian Ocean shores.

Sandy/muddy shores, which often contain seagrass beds, are economically important, particularly in relation to fisheries, since it is known that many economically important fishes spend at least their larval stages in these habitats (Fortes, 1988). Such shores also have great economic value as tourist attractions, though ironically, tourism, particularly if mismanaged, often results in the degradation of these same shores.

Biotic and abiotic factors of Dar es Salaam sandy/muddy shores, tend to vary with the degree of exposure of the beach, the location of the beach and the time of the year (Mwaiseje, 1973).

Beaches along the Dar es Salaam coast have been subjected to many anthropogenic impacts such as beach seining; beach walking; boat grounding and anchoring; collection of shellfish, star fish and sea cucumbers for decoration or food; waste disposal and pollution. These human impacts are on-going and are likely to increase unless definite steps are made to reduce or mitigate them.

Numerous studies on intertidal benthic ecology have been conducted all over the world, with the focus often being on investigating the vertical zonation of organisms and the factors controlling such zonation. Often the zones are described in terms of the dominant organisms. Xu et al. (1992), studying the sandy beach of Hainan Island,
China, observed that there were three main zones: a gammaridean zone, dominated by the amphipod, *Talorchestia britoi*; an isopod zone, dominated by *Excirrograna japonica*; and a clam-gastropod zone, dominated by *Gomphina aequilata* and *Umbonium vestiarium*. The study showed that tides, substratum type, salinity and wave action were the main factors controlling vertical distribution of benthic fauna.

Alongi (1990) reported the community structures of benthos in tropical intertidal habitats (excluding mangroves and coral reefs). In the exposed sandy beaches of Gold Coast, North West Africa, the dominant species are *Donax pulchellus* (bivalve), *Excirrograna latipes* (isopod), and *Urothoe grimaldi* (amphipod). In moderately exposed sandy beaches in Mombasa, Kenya, the dominant organisms are amphipods and isopods. In moderately exposed sandy flats in Singapore, the dominant species found are *Cerithidea cingulata* (gastropod), *Clithon oculalensis* (gastropod) and *Ceratonereis hircincola* (polychaete). The protected sandy beaches of Mombasa are mainly inhabited by isopods. Polluted sandy beaches in San Luis, Venezuela are dominated by *Emerita holthuisii* (decapod) and *Donax denticulatus* (bivalve).

It is clear that trends in faunal communities are similar for tropical and temperate habitats. One of the important trends observed is that faunal densities are lowest in exposed coarse sandy beaches, whether in tropical or temperate habitats (Alongi, 1990).

Grain size is thus a very important factor determining faunal distribution and abundance in all geographical areas. Grain size composition is influenced by numerous environmental factors, such as exposure to wave action, currents, and the nature and amount of suspended matter (Moore, 1958).

It has been 25 years since Mwaiseje (1973) conducted a study of some aspects of the ecology of certain sandy/muddy shores in the Dar es Salaam area and it is interesting to see what changes have occurred during that period. Therefore, the research objectives of this study were: (1) to study the ecological factors, both abiotic and biotic, of the intertidal zone of selected sandy/muddy shores in the Dar es Salaam area (Kunduchi, Ocean Road, Mjobwema/Kendwa and Mtoni), (2) to study the vertical zonation on these four shores, and (3) to determine the relationships between environmental factors and the distribution and abundance of organisms on the four shores.

**MATERIALS AND METHODS**

**Study sites**

The study sites (Figure 1) were selected in such a way that different degrees of exposure to wave action are represented. The most exposed shore is Kunduchi, followed by Mjobwema/Kendwa and Ocean Road (Mwaiseje, 1973). Mtoni is the most sheltered from wave action and ocean currents since it is within an estuary. However, it is subjected to tidal movement and, seasonally, it can be subjected to rapid river flow.
Figure 1. Map of the Dar es Salaam study area showing the locations of the four study sites

Kunduchi Beach

Kunduchi beach is about 20km north of Dar es Salaam city centre, at 6° 40' S and 9° 13' E. The beach is partially protected from strong open sea waves by a discontinuous line of islands offshore, including Bongoyo, Pangavini and Mbudya. This sandy beach is long, being about 500m from the high tide to the low tide mark. The beach is an important area to the local fishing communities and is a tourist attraction.
Ocean Road Beach
Ocean Road beach is located at 6° 49' S, 39° 19' E, and is on the northern side of the harbour, just outside the entrance. From the harbour mouth, the beach extends northwards to the mouth of Msimbazi Creek where the substrate becomes predominantly muddy. The upper part of the shore consists of a short, steep sandy slope. Below this is a sandy/muddy flat which extends far offshore during extreme low water springs. The lower eulittoral zone is characterised by patches of seagrasses and algae.

Mjimwema/Kendwa Beach
This beach is about 4km south of Dar es Salaam harbour at 6° 50' S, 39° 21' E. It has a very short, steep sandy slope, below which is a long sandy/muddy intertidal flat which never drains completely even during very low tides and which extends all the way out to Kendwa Island, approximately 930m offshore. The beach is protected from the waves of the open sea not only by Kendwa Island, but also by a line of discontinuous islands on either side, namely, Outer and Inner Makatumbe, and Outer and Inner Sinda.

The beach on the landward side is sandy, while the shore at Kendwa Island is very rocky. The sandy/muddy flat is scattered with slightly raised rocky patches. An oil pipe runs from the TIPER (Tanzania Italian Petroleum Refinery) plant via Mjimwema Beach to Kendwa Island where ships dock to unload oil. Therefore, this beach could be important for studies related to oil pollution in the event of leakage.

Mtoni
The selected site at Mtoni is located where Mtoni Creek enters the Mtoni estuary near Mbagala, at a distance of about 10km south of Dar es Salaam city centre, at 6° 45' S and 39° 41' E. Mangrove trees are found on both sides of the creek, covering a distance of approximately 1.5km. The creek is about 2m deep at low tide. A large part of the area is muddy. Fishing activities are conducted in this area, mainly for shrimps and edible crabs.

Research design and sampling
On each of the selected shores, a permanent transect was identified, marked and utilised for sampling throughout the study period. On each shore, a 20m strip along the permanent transect line, i.e. 10m on each side, was sampled. Along the steep sandy slope on each shore, sampling stations were measured off every 10m. Along the sandy/muddy flat, sampling stations were 10m apart at Mtoni, 20m apart at Kunduchi and Ocean Road, and 50m apart at Mjimwema/Kendwa. Thus, the vertical distances between sampling stations were approximately equal. At each sampling station, samples were taken at random points along an axis perpendicular to the transect line, i.e. across the 20-m strip, by using a random number table. The same sampling stations were measured off for every sampling session, but different random sampling points were selected each session. During each sampling session, one to three random samples were taken
at each sampling station, depending upon the factor being measured, as described in the sections below.

Sampling was conducted on all shores once every lunar month, at low tide, during spring tides. Organisms were sampled during every sampling session as well as some of the physical and chemical factors. Other abiotic factors were sampled only occasionally as described in each section below. Other variations from the general sampling design are described in the relevant sections below.

**Substrate analysis**

Along each transect on each shore, substrate samples were collected every lunar month for particle size analysis and for the determination of percentage pore water and organic matter content.

Sediment samples were collected using a 3.5cm corer inserted into the substratum to a depth of 13cm. In the laboratory, the core samples were oven-dried at 40°C. The different sediment particle sizes were separated using a series of sieves, ranging from 8mm to less than 0.063mm, mounted on a mechanical shaker. The residues in each sieve were weighed and the median grain size of each sample was determined using the method described by Griffiths (1967) and Buchanan and Kain (1971).

Once every month, sediment samples were collected at each sampling station. From each sample, a known weight of saturated sediment was dried in an oven at 105°C to constant weight. The percentage loss in weight was calculated to determine percentage pore water. Each sample was then ignited at 500°C for 6 hours and cooled in a desiccator. The loss in dry weight was measured and organic matter content expressed as a percentage (Parsons et al., 1989).

**Salinity**

Once each month, salinity was measured along the permanent transect on each shore. At sampling stations where there were tidal pools, three random samples of tidal pool water were taken along an axis perpendicular to the transect line and salinity was measured using a refractometer.

**Dissolved oxygen concentration in tidal pool water**

Each month dissolved oxygen concentration was measured along the permanent transect on each shore. At sampling stations where there were tidal pools, one sample of tidal pool water was taken at a random point along the axis perpendicular to the transect line. The Winkler method for measuring dissolved oxygen was utilised (Parsons et al., 1989).

**Biotic factors**

At each sampling station, three random sampling points were selected along an axis perpendicular to the transect line. At each sampling point, a 0.25 x 0.25m quadrat was laid down. The sediment was dug out to a depth of 40 cm (Day, 1958; McIntyre, 1968)
and sieved through a 2.0mm mesh sieve. Specimens were collected alive and placed in plastic containers. In the laboratory, specimens were sorted out according to major taxa and killed by the addition of 10% saline formalin. For certain specimens for which identification depends upon extrusion of jaws, e.g. nereids and some other polychaetes, 5% formalin was added drop by drop for one hour from a burette (Day, 1967). Qualitative sampling was also done by collecting other organisms observed outside the quadrats.


All individuals of the same species or taxon found in each quadrat were placed together and counted to determine density. Specimens were dried in an oven at 105°C to constant weight and cooled in a desiccator for at least 30min. The dry weight of each species/taxon per quadrat was recorded to the nearest 0.0001g to determine biomass. For shelled animals such as gastropods, after drying, the shells were removed before taking the dry weight of the tissue.

RESULTS

Abiotic factors

Meteorological factors
The mean monthly maximum temperature was highest in January (32.0°C) and lowest in June (28.6°C), while mean monthly minimum temperature was highest in January (24.6°C) and lowest in August (17.4°C). The mean monthly rainfall over the study period showed that rainfall was highest during March (282.8mm) with a secondary peak during October (108.1mm). Rainfall was lowest during February (0.3mm).

Substrate analyses
At Kunduchi, the supralittoral fringe had medium to coarse sand, whereas the upper and middle midlittoral zones had predominantly fine sand and the lower midlittoral zone had very fine sand (Table 1). The substrate was moderately well sorted in all other zones.

At Ocean Road, the upper sandy slope had medium sand, while the sandy/muddy flat contained very fine sand. While the substrate was poorly sorted in the supralittoral fringe, it was moderately well sorted on the rest of the beach.

At Mjiemwema, the supralittoral fringe contained medium sand particles which were poorly sorted, whereas the upper and middle midlittoral zones contained fine sand that was moderately well sorted. At the Kendwa Island side of the transect, the supralittoral fringe is rocky; therefore, only the upper midlittoral zone substrate was analysed and was found to contain coarse sand, which was very poorly sorted.
Table 1. Particle size determination (July 1996) (all units in phi)

<table>
<thead>
<tr>
<th>Shore</th>
<th>Zone</th>
<th>Q1</th>
<th>MD</th>
<th>Q3</th>
<th>QD</th>
<th>Remarks</th>
<th>SK</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kunduchi</td>
<td>Supralittoral</td>
<td>1.40</td>
<td>1.80</td>
<td>2.20</td>
<td>0.60</td>
<td>Moderately well sorted</td>
<td>0.20</td>
<td>Medium sand</td>
</tr>
<tr>
<td></td>
<td>Upper midlittoral</td>
<td>2.20</td>
<td>2.35</td>
<td>3.50</td>
<td>0.65</td>
<td>Moderately well sorted</td>
<td>0.50</td>
<td>Fine sand</td>
</tr>
<tr>
<td></td>
<td>Mid midlittoral</td>
<td>2.50</td>
<td>2.90</td>
<td>3.50</td>
<td>0.50</td>
<td>Moderately well sorted</td>
<td>0.10</td>
<td>Fine sand</td>
</tr>
<tr>
<td></td>
<td>Lower midlittoral</td>
<td>4.10</td>
<td>4.25</td>
<td>4.80</td>
<td>0.35</td>
<td>Well sorted</td>
<td>0.20</td>
<td>Coarse silt</td>
</tr>
<tr>
<td>Ocean Road</td>
<td>Supralittoral</td>
<td>1.50</td>
<td>2.80</td>
<td>4.50</td>
<td>1.50</td>
<td>Poorly sorted</td>
<td>0.20</td>
<td>Medium sand</td>
</tr>
<tr>
<td></td>
<td>Upper midlittoral</td>
<td>2.00</td>
<td>1.40</td>
<td>3.40</td>
<td>0.70</td>
<td>Moderately well sorted</td>
<td>0.00</td>
<td>Medium sand</td>
</tr>
<tr>
<td></td>
<td>Mid midlittoral</td>
<td>3.50</td>
<td>4.35</td>
<td>4.60</td>
<td>0.55</td>
<td>Moderately well sorted</td>
<td>-0.30</td>
<td>Coarse silt</td>
</tr>
<tr>
<td></td>
<td>Lower midlittoral</td>
<td>2.30</td>
<td>3.00</td>
<td>3.30</td>
<td>0.50</td>
<td>Moderately well sorted</td>
<td>-0.20</td>
<td>Very fine sand</td>
</tr>
<tr>
<td>Mjimwema/Kendwa Beach</td>
<td>Supralittoral</td>
<td>0.50</td>
<td>2.00</td>
<td>3.50</td>
<td>1.50</td>
<td>Poorly sorted</td>
<td>0.00</td>
<td>Fine sand</td>
</tr>
<tr>
<td></td>
<td>Upper midlittoral</td>
<td>1.10</td>
<td>1.80</td>
<td>2.30</td>
<td>0.60</td>
<td>Moderately well sorted</td>
<td>-0.10</td>
<td>Fine sand</td>
</tr>
<tr>
<td></td>
<td>Mid midlittoral</td>
<td>2.20</td>
<td>3.10</td>
<td>3.40</td>
<td>0.60</td>
<td>Moderately well sorted</td>
<td>-0.30</td>
<td>Fine sand</td>
</tr>
<tr>
<td></td>
<td>Upper midlittoral</td>
<td>1.10</td>
<td>2.00</td>
<td>3.30</td>
<td>1.10</td>
<td>Very poorly sorted</td>
<td>0.20</td>
<td>Coarse sand</td>
</tr>
<tr>
<td>Mtoni</td>
<td>Supralittoral</td>
<td>3.10</td>
<td>3.50</td>
<td>4.90</td>
<td>0.90</td>
<td>Moderately well sorted</td>
<td>0.50</td>
<td>Medium sand</td>
</tr>
<tr>
<td></td>
<td>Upper midlittoral</td>
<td>2.20</td>
<td>4.55</td>
<td>6.80</td>
<td>2.30</td>
<td>Poorly sorted</td>
<td>-0.05</td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td>Lower midlittoral</td>
<td>1.30</td>
<td>4.50</td>
<td>6.50</td>
<td>2.60</td>
<td>Very poorly sorted</td>
<td>-0.60</td>
<td>silt</td>
</tr>
</tbody>
</table>

Q1 = Lower quartile (value corresponds to 25%)
MD = Median particle diameter (value corresponds to 50%)
Q3 = Upper quartile (value corresponds to 75%)
QD = Quartile Deviation
SK = Skewness (indicates preponderance of grain size fraction either larger (+ve) or small (-ve) than the MD).

Of all the shores, Mtoni had the finest substrate, consisting of fine sand in the supralittoral zone and silt in the other zones. The substrate was moderately well sorted in the supralittoral fringe, but very poorly sorted in the other zones.

By far the lowest percent pore water occurred at Mtoni, where it ranged from 0.9 to 1.7%. Percent pore water was 2.5–4.1% at Kunduchi, 2.2–4.2% at Ocean Road and 2.6–4.3% at Mjimwema.
Mtoni had the highest organic matter content throughout the year, ranging from 11.8 to 15.3%, while Mjiwmewa had the lowest organic matter content (3.5–4.8%). Kunduchi and Ocean Road had similar organic matter content, measuring 4.3–8.3% and 4.8–8.3%, respectively.

**Salinity**
Throughout most of the year, salinity on other shores remained close to 35‰, while at Mtoni, salinity ranged from 29 to 32.5‰. During the rainy period in March and April, salinity on other shores dropped to between 20 and 30‰, while at Mtoni it dropped to 20‰ during both months.

**Dissolved oxygen concentration in tidal pool water**
Throughout the year, dissolved oxygen concentration was higher at Mtoni (5.7–7.4ml/l) than at the other shores (which ranged between 4.1–6.5ml/l). On all shores the tidal pool oxygen concentration was highest during the rainy period in March, April and May and lowest during December and January.

**Biotic factors**

*Comparison of the four shores*

Total faunal density (monthly means) on the four shores over the one-year study period is shown in Figure 2. Randomised block analysis of variance showed that there was a very significant difference in density among the four shores (F = 22.751, p = 3.609 x 10^{-6}). The Student-Newman-Keuls (SNK) test showed that Mtoni had a significantly greater density than the other three shores (as can also be observed in the graph), but the latter three were not significantly different from each other (Table 2).

Total faunal biomass (monthly means) on the four shores over the one-year study period is shown in Figure 3. Friedman’s test showed that there was a very significant difference in biomass among the four shores (Chi-square = 23.900, p = 2.576 x 10^{-5}). A nonparametric multiple comparisons test (Zar, 1984) showed that Mjiwmewa, followed by Mtoni, had the greatest biomass of fauna (Table 2).

Friedman’s test showed that there was a very significant difference in the biomass of four major taxonomic groups, i.e. polychaetes, crabs, gastropods and bivalves, among the four shores (Table 3). A nonparametric multiple comparisons test (Table 4) showed that there was a significantly greater biomass of bivalves and crabs at Mtoni than on the other shores. Gastropods had the greatest biomass at Mjiwmewa and were not observed at all at Mtoni. Mtoni had the greatest biomass of polychaetes, though it was only significantly greater than the biomass at Mjiwmewa.

The species richness, evenness and species diversity (calculated using the Shannon-Weaver index) for each shore is given in Table 5, while the results of a t-test (Zar, 1984) for difference in species diversity between pairs of shores is shown in Table 6. Mjiwmewa had significantly greater species diversity than all other shores. There was no significant
Figure 2. Mean monthly density of fauna on all shores during all months (data for all vertical zones combined)

Table 2. Results of the Student-Newman-Keuls test and a non-parametric multiple comparisons test for difference in density and biomass, respectively, between pairs of shores (for each shore n = 12)

<table>
<thead>
<tr>
<th>Shore Mean density (no./0.0625m²)</th>
<th>KU</th>
<th>OR</th>
<th>MJ</th>
<th>MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in density</td>
<td>16.93</td>
<td>19.9</td>
<td>27.3</td>
<td>100.1</td>
</tr>
<tr>
<td>Difference in biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shore Rank-sum of biomass</td>
<td>19.0</td>
<td>22.0</td>
<td>32.0</td>
<td>47.0</td>
</tr>
<tr>
<td>KU = Kunduchi; OR = Ocean Road; MJ = Mjimwema; MT = Mtoni</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Bold lines underneath means / Rank-sums join those of shores that are not significantly different at p = 0.05, but break between those that are significantly different.
Figure 3. Mean monthly biomass of fauna on all shores during all months (data for all vertical zones combined)

<table>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Test statistic</th>
<th>DF</th>
<th>p</th>
<th>Significance of difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polychaetes</td>
<td>18.600</td>
<td>3</td>
<td>3.30 x 10^{-4}</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>Crabs</td>
<td>19.800</td>
<td>3</td>
<td>1.86 x 10^{-4}</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>Gastropods</td>
<td>32.700</td>
<td>3</td>
<td>7.60 x 10^{-8}</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>Bivalves</td>
<td>24.700</td>
<td>3</td>
<td>1.74 x 10^{-5}</td>
<td>v.s.d.</td>
</tr>
</tbody>
</table>

v.s.d. = very significant difference

difference in diversity between Kunduchi and Ocean Road, while Mtoni had significantly lower species diversity than all other shores.

**Vertical distribution of organisms**

The dominant organisms in each vertical zone are indicated in the profiles in Figures 4 to 7 for Kunduchi, Ocean Road, Mjimwema and Mtoni, respectively. A few of the common species (grouped according to classes) found in each zone are given in Table 7. For analysis, the shores are divided into five zones (Doty, 1957): the supralittoral fringe (the upper part of the steep sandy slope), the upper midlittoral zone (the lower part of
Table 4. Results of non-parametric multiple comparisons tests for difference in biomass of major taxonomic groups between pairs of shores (for each shore, n = 12)

<table>
<thead>
<tr>
<th>Shore</th>
<th>Method</th>
<th>MJ</th>
<th>KU</th>
<th>OR</th>
<th>MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polychaetes</td>
<td>Rank-sum</td>
<td>15.0</td>
<td>29.0</td>
<td>35.0</td>
<td>41.0</td>
</tr>
<tr>
<td>Crabs</td>
<td>Rank-sum</td>
<td>23.0</td>
<td>23.0</td>
<td>27.0</td>
<td>47.0</td>
</tr>
<tr>
<td>Gastropods</td>
<td>Rank-sum</td>
<td>12.0</td>
<td>26.0</td>
<td>35.0</td>
<td>47.0</td>
</tr>
<tr>
<td>Bivalves</td>
<td>Rank-sum</td>
<td>19.0</td>
<td>23.0</td>
<td>30.0</td>
<td>48.0</td>
</tr>
</tbody>
</table>

Note: Bold lines underneath means / Rank-sums join those of shores which are not significantly different at p= 0.05, but break between those that are significantly different.
KU = Kunduchi; OR = Ocean Road; MJ = Mjimwema; MT = Mtoni

Table 5. Species richness, evenness and species diversity (Shannon-Weaver index) in the four study sites

<table>
<thead>
<tr>
<th>Shore</th>
<th>No. of species</th>
<th>Evenness</th>
<th>Species diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kunduchi</td>
<td>121</td>
<td>0.9856</td>
<td>2.0527</td>
</tr>
<tr>
<td>Ocean Road</td>
<td>122</td>
<td>0.9846</td>
<td>2.053</td>
</tr>
<tr>
<td>Mjimwema</td>
<td>138</td>
<td>0.9845</td>
<td>2.1067</td>
</tr>
<tr>
<td>Mtoni</td>
<td>35</td>
<td>1.0000</td>
<td>1.5441</td>
</tr>
</tbody>
</table>

Table 6. Results of t-tests for difference in species diversity between pairs of shores (diversity indices shown in Table 5)

<table>
<thead>
<tr>
<th>Comparisons</th>
<th>Test statistic (t)</th>
<th>p</th>
<th>Significance of difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>KU vs OR</td>
<td>-0.0220</td>
<td>&gt;0.50</td>
<td>n.s.d.</td>
</tr>
<tr>
<td>KU vs MJ</td>
<td>-3.6641</td>
<td>&lt;0.001</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>KU vs MT</td>
<td>26.9300</td>
<td>&lt;0.001</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>OR vs MJ</td>
<td>-3.8134</td>
<td>&lt;0.001</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>OR vs MT</td>
<td>27.63</td>
<td>&lt;0.001</td>
<td>v.s.d.</td>
</tr>
<tr>
<td>MJ vs MT</td>
<td>28.87</td>
<td>&lt;0.001</td>
<td>v.s.d.</td>
</tr>
</tbody>
</table>

n.s.d. = no significant difference;

v.s.d. = very significant difference
KU = Kunduchi; OR = Ocean Road; MJ = Mjimwema; MT = Mtoni

the steep sandy slope), the middle midlittoral and lower midlittoral zones (the sandy/muddy flat) and the sublittoral fringe (lower zone) where tidal pools are continuous and exposure is confined to extreme low water of spring tides only.
Figure 4. Shore profile of Kunduchi study site indicating the dominant organisms in each vertical zone (A=supralittoral fringe; B=upper midlittoral zone; C= middle midlittoral zone; D=lower midlittoral zone)
Figure 5. Shore profile of Ocean Road study site indicating the dominant organisms in each vertical zone (A=supralittoral fringe; B=upper midlittoral zone; C= middle midlittoral zone; D=lower midlittoral zone)
Figure 6. Shore profile of Mjimwema study site indicating the dominant organisms in each vertical zone (A=supralittoral fringe; B=upper midlittoral zone; C= middle midlittoral zone; D=lower midlittoral zone)
Figure 7. Shore profile of Mtorni study site indicating the dominant organisms in each vertical zone (A=supralittoral fringe; B=upper midlittoral zone; C= middle midlittoral zone; D=lower midlittoral zone).
Table 7. Common species (class given in parentheses) found in each vertical zone on the four shores

<table>
<thead>
<tr>
<th>Zone</th>
<th>Kunduchi</th>
<th>Ocean Road</th>
<th>Mjimwema</th>
<th>Mtoni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supralittoral</td>
<td>(Pe) Donax faba</td>
<td>(Pe) Donax faba</td>
<td>(Pe) Donax faba</td>
<td>(Cr) Dotila fenestraeta</td>
</tr>
<tr>
<td>fringe</td>
<td>(Pe) Donax sp.</td>
<td>(Pe) Dotila fenestraeta</td>
<td>(Pe) Donax sp.</td>
<td>(Cr) Uca spp.</td>
</tr>
<tr>
<td></td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Cr) Dotila fenestraeta</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td></td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Pe) Donax faba</td>
<td>(Pe) Arcuatula arcuata</td>
</tr>
<tr>
<td>midlittoral</td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Pe) Donax faba</td>
<td>(Pe) Modiolus sp.</td>
</tr>
<tr>
<td></td>
<td>(Pe) Donax faba</td>
<td>(Ga) Cyprea annulus</td>
<td>(Cr) Dotila fenestraeta</td>
<td>(Po) Sthenelais boa</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Nassa arcularia</td>
<td>(Cr) Uca spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Macoma littoralis</td>
<td>(Cr) Ocypode ryderi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cr) Arcuatula arcuata</td>
<td>(Pe) Macoma littoralis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Cyprea annulus</td>
<td>(Pe) Tellina rugosa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cr) Cyprea tigris</td>
<td>(Pe) Anadara antiquata</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>(Po) Sthenelais boa</td>
<td>(Cr) Clibanarius longitursus</td>
<td>(Cr) Thalamita prynna</td>
<td></td>
</tr>
<tr>
<td>midlittoral</td>
<td>(Cr) Coenobita rugosus</td>
<td>(Po) Macoma littoralis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Si) Golfingia capsensis</td>
<td>(Po) Tellina rugosa</td>
<td>(Ga) Cyprea annulus spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Si) Siphonosoma cumanensis</td>
<td>(Pe) Anadara antiquata</td>
<td>(Ga) Cyprea annulus</td>
<td>(Po) Dendroneresis</td>
</tr>
<tr>
<td></td>
<td>(Cr) Clibanarius longitursus</td>
<td>(Ga) Cyprea tigris</td>
<td>(Cr) Thalamita crenata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Cr) Coenobita rugosus</td>
<td>(Po) Macrophthalmus spp.</td>
<td>(Cr) Thalamita crenata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Cr) Portunus pelagicus</td>
<td>(Pe) Solen correctus</td>
<td>(Ga) Strombus spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Macoma littoralis</td>
<td>(Ga) Sthenelais boa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Tellina rugosa</td>
<td>(Pe) Sthenelais boa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cr) Macrophthalmus spp.</td>
<td>(Cr) Macrthasms spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Moediolus spp.</td>
<td>(Cr) Coenobita rugosus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Eucenicetra mathaei</td>
<td>(Ho) Bohadschia vitiensis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Cyprea annulus</td>
<td>(Ho) Cucumaria spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Cyprea erosa</td>
<td>(Pr) Grantessa ramosa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cr) Cyprea annulus</td>
<td>(Pr) Leucosolenia spp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Polinices mammilla</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ga) Strenbus spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Eurythoe complanata</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Po) Sthenelais boa</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cr) Macrthasms spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Pe) Sthenelais boa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>(Ho) Bohadschia vitiensis</td>
<td>(Pe) Anadara antiquata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>midlittoral</td>
<td>(Ho) Holothuria scabra</td>
<td>(Pe) Macoma littoralis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Ho) Cucumaria spp.</td>
<td>(Pe) Tellina rugosa</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Cr) Macrophthalmus spp.</td>
<td>(Pe) Moediolus spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Pe) Macoma littoralis</td>
<td>(Pe) Moediolus pulex</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Ga) Cyprae annulus</td>
<td>(Cr) Macrophthalmus sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ho) Holothuria scabra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classes are according to Day (1969): Pr = Porifera (sponges), Ac = Actiniaria (sea anemone), Ne = Nemertea, Sl = Sipunculida, Po = Polychaeta, Cr = Crustacea, Pe = Pelecypoda (Bivalvia), Ga = Gastropoda, Op = Ophiuroidea, Ec = Echinoid, Ho = Holothuroidea.</td>
<td>Continued next page</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Continued

<table>
<thead>
<tr>
<th>Zone</th>
<th>Kunduchi</th>
<th>Ocean Road</th>
<th>Mjimwema</th>
<th>Mtoni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper midlittoral (Kendwa)</td>
<td>(Ac) Palythoa natalensis</td>
<td>(Ga) Cypraea annulus</td>
<td>(Ga) Drupa spp.</td>
<td>(Cr) Uca spp.</td>
</tr>
<tr>
<td></td>
<td>(Ga) Drupa squamosa</td>
<td>(Cr) Macrophthalmus spp.</td>
<td>(Cr) Thalamita spp.</td>
<td>(Cr) Cibanarius longitarsus</td>
</tr>
<tr>
<td></td>
<td>(Cr) Coenobita rugosus</td>
<td></td>
<td>(Cr) Coenobita rugosus</td>
<td></td>
</tr>
</tbody>
</table>

Classes are according to Day (1969): Pr = Porifera (sponges), Ac = Actiniaria (sea anemone), Ne = Nemertea, Si = Sipunculida, Po = Polychaeta, Cr = Crustacea, Pe = Pelecypoda (Bivalvia), Ga = Gastropoda, Op = Ophiuroidea, Ec = Echinoidea, Ho = Holothuroidea.

On all shores, crabs dominated the sandy upper shore. *Dotilla fenestrata* was dominant on all shores along with either *Ocypode* spp. (Kunduchi, Ocean Road and Mjimwema) or *Uca* spp. (Mtoni).

At Kunduchi and Ocean Road, the midshore was dominated by a variety of polychaetes, sipunculids, bivalves and crabs, while holothurians dominated the lower shore.

At Mjimwema, the midshore was dominated by a variety of gastropods, bivalves, sponges, holothurians, sea urchins and brittle stars. There is no lower midlittoral zone or sublittoral fringe since the shoreline rises towards Kendwa Island. The shore at Kendwa is rocky, dominated by crabs and gastropods, with colonial sea anemones (*Palythoa natalensis*) dominating the lower part.

At Mtoni, the midshore was dominated by bivalves (*Arcuatula arcuatula* and *Modiolus* sp.) and crabs.

**Vertical distribution at Kunduchi**

In the supralittoral fringe, the fauna consisted mainly of the bivalves *Donax fava* and *Donax* sp., and the crustaceans *Dotilla fenestrata*, *Emerita austroafricana*, and *Ocypode kuhli* were noted occasionally.

In the middle midlittoral zone, where there were scattered shallow tidal pools, the common species were polychaetes, such as *Sthenelais boa*, *Streblosoma persica*, and *Eurythoe complanata*, *Dendronereis* spp. and *Ceratonereis* spp.; sipunculids, such as *Golfingia capensis* and *Siphonosoma cumanensis*; hermit crabs, like *Cibanarius longitarsus* and *Coenobita rugosus* and swimming crabs such as *Portunus pelagicus* and *Emerita austroafricana*. Other crustaceans were *Thalamita crenata* and *Macrophthalmus* spp. Bivalve species found in this zone at low density were *Tellina rugosa*, *Macoma littoralis*, *Cardium flavum*, *Anadara antiquata* and *Solen* spp., while gastropod species included *Cypraea annulus* (very common), *Polinices mammila*, *Nassarius pullus*, *N. coronatus*, *Natica* spp. and *Conus abraeaus*.

In the lower midlittoral zone, most of the species found were the same as those found in the zone just mentioned. However, additional species were found such as the
holothurians Bohadschia vitiensis, Holothuria scabra, H. alba, Thyone aurea, and Cucumaria spp. and, occasionally, the starfish Protoreaster lincki and Asterina burtoni. The fauna which were found in the highest density were crabs.

**Vertical distribution at Ocean Road**

In the terrestrial area above the supralittoral fringe, the creeping Cucurbitacea grass Ipomoea pes-caprae was common. The supralittoral zone was dominated by Donax faba and Dotilla fenestrata. Ocypode kuhli was found only occasionally.

In the upper midlittoral zone, there were dead shells of gastropods and bivalves and washed in floral species. The species found in this zone were the same as those in the supralittoral fringe with some additional species of gastropods, such as Cypraea annulus and Nassa arcularia and bivalves such as Macoma littoralis.

In the sandy/muddy flat, i.e. the middle and lower midlittoral zones, where scattered tidal pools were found, the dominant fauna were hermit crabs, such as Clibanarius longitursus and Coenobita rugosus; swimming crabs, such as Portunus pelagicus and Emerita eustroafricanus; and other crabs, such as Thalamita spp., Macrophthalmus spp. and Scylla serrata. Other species found in this zone were bivalves, i.e. Anadara antiquata, Macoma littoralis, Tellina rugosa, Solen correctus, S. capensis, S. aspersus, Modiolus spp., M. pulex, Artina vexillum, Pinna bicolor and Cardium flavum. In this zone also some gastropods were found like Cypraea annulus, C. erosa, Nassa spp., Nassarius spp. and Strombus spp. Holothurians were found in tidal pools in the lower midlittoral zone. These included Holothuria scabra, H. alba, Bohadschia vitiensis, Thyone aureus, and Cucumaria sykion.

Polychaetes species found at various levels on this shore were Sthenelais boa, Eurythoe complanata and Magelona spp. Only a few species of sipunculids were found, such as Golfingia capensis, and only one species of Nemertea, i.e. Cerebratulus fuscus.

**Vertical distribution at Mjimwema/Kendwa**

The supralittoral fringe was dominated by Donax faba, Donax spp., Dotilla fenestrata, and few species of Ocypode.

On the lower part of the steep sandy slope, i.e. in the upper midlittoral zone, the species found included Donax faba, Donax spp., Dotilla fenestrata, Uca spp. and Ocypode ryderi (formerly Ocypode kuhli, corrected by Vannini, 1976). Bivalves such as Macoma littoralis and Tellina rugosa were also found in this zone just above the sandy/muddy flat.

Most of the sandy/muddy flat, which is entirely in the middle midlittoral zone, does not dry up, even during low springtide. Thus, for the most part, it was covered by seagrass beds intermixed with algae, which formed a suitable habitat for many species of benthic fauna. Bivalves such as Macoma littoralis, Tellina rugosa and Anadara antiquata were found in high density, while Cardium flavum, Modiolus pulex, Modiolus sp. and Solen spp. were found only occasionally. Gastropods species found in this zone were Cypraea annulus (very common), C. tigris, C. erosa, C. monata, Nassarius spp., Strombus spp., Conus ebraeus and C. vexillum. Two species of gastropods without shells were
also found in tidal pools amongst seagrasses, namely, *Aplysia dactycomela* and *A. maculata*. Sea urchins were found particularly in the middle part of the sandy/muddy flat amongst the seagrass and algae. The sea urchins *Echinometra mathaei* occurred at high density, while *Stomopneustes variolaris* and *Prionocidaris baculasa* were found only occasionally. Brittle stars were often found close to the sea urchins. In particular, *Ophiothrix triglochis*, *Ophiocoma scolopendrina* and *Macrophthirix hirsuta* were very common. *Ophiocoma erinaceus* was found occasionally under boulders. The nemertean species which was occasionally found was *Cerebratulus fuscus*. A few polychaetes species occurred in very low abundance in the seagrass beds, namely, *Eurythoe complanata* and *Sthenelais boa*. The crabs of this zone were *Thalamita* spp. (found in tidal pools), *Macrophthalmus bosci*, *Macrophthalmus* spp. (found under stones), and hermit crabs such as *Clibanarius longitarsus*, *Dardanus* spp. and *Diogenes avarus*. Holothurians, found in shallow tidal pools, were *Holothurian conusalba*, *H. scabra*, *H. edulis*, *H. atra*, *H. leucospilota*, *Bohadschia vitiensis*, *Cucumaria sykion*, *C. spyridophora* and *Thyone aureus*. The sponges identified were *Leucosolenia* spp., *Grantessa ramosa*, *Sycon* spp. and *Clatharia* spp. Starfish were occasionally found including *Actinopyra mauriana*, *Marthasterias glacialis* and *Asterina exigua*.

The upper midlittoral zone on the rocky shore at Kendwa was almost completely dominated by large mats of the colonial sea anemone, *Palythoa natalensis*. The higher parts of this rocky shore were inhabited by gastropods such as *Cyprea annulus*, *Drupa squamosa*, *Drupa* spp. and crabs, such as *Uca* spp., *Macrophthalmus* spp., *Thalamita* spp. and hermit crabs.

**Vertical distribution at Mtoni**

On this shore, only the supralittoral fringe is sandy. Other zones are typically muddy. The supralittoral zone was dominated by *Dotilla fenestrata*, which was found in very high densities. Other crabs observed included *Uca* spp. A few *Donax faba* were found.

The muddy flat supports large numbers of a bivalve identified as *Arcuatula arcuatula*, together with *Modiolus* sp., both of which form a very thick layer covering a large part of the muddy flat. These species are very small in size. Only a few other species were found such as the polychaetes *Sthenelais boa*, *Eurythoe complanata*, *Magelona* sp., *Streblosoma persica*, *Dendronereis* sp. and *Ceratonereis* sp.; the crabs *Thalamita prynna*, *Thalamita crenata*, *Uca marionis* and *Macrophthalmus* spp., the nemerteans *Cerebratulus fuscus*, the bivalve *Solen aspersus* and one sipunculid species which was not identified. In this shore, gastropods and seagrasses were not found. Only one species of algae, *Ulva* spp., was found in the middle midlittoral zone.

**DISCUSSION**

**Abiotic factors**

The physical and chemical characteristics of Kunduchi and Ocean Road shores are similar in many ways. They have medium sand on the upper shore, fine sand in the
middle of the shore and very fine sand on the lower part of the shore. Generally the substrate is moderately well sorted throughout, except that it is poorly sorted in the supralittoral fringe at Ocean Road. They have almost the same seasonal variations in percent pore water, organic matter content, dissolved oxygen and salinity. One noticeable difference, however, is that there was a considerable drop in salinity at Kunduchi during the rainy season as compared to Ocean Road. Both percent pore water and organic matter content are low on the steep sandy slopes of these shores and then rise to almost a constant level throughout their sandy/muddy flats.

On the Mjimwema/Kendwa beach, throughout the sandy/muddy flat which covers a distance of 900m, the particle size is moderate (fine sand) and substrate is moderately well sorted. In comparison with Kunduchi and Ocean Road, it has higher percent pore water, lower organic matter content, but approximately the same dissolved oxygen and salinity levels. A unique feature of Mjimwema/Kendwa is that, due to the physical contours of the surrounding area, this shore never completely drains even during low spring tides. The substratum is always covered with water and therefore it is protected from desiccation.

Mtoni is quite different from the other three shores. The substrate is very fine (silt). Since it is very poorly sorted, the percent pore water is very low. Being in an estuary, it has a high build up of organic matter. Salinity is lower than on the other shores and shows the greatest drop during the rainy season when there was extensive runoff from the surrounding catchment area into the estuary.

**Biotic factors**

The biological status of Kunduchi and Ocean Road shores was found to be similar, as were the abiotic factors. Both had moderate species diversity, but low density and biomass of macrofauna. The low abundance is probably partly due to environmental stress from desiccation. Large areas of these shores drain during low tides. Besides this, there are several anthropogenic impacts. At both sites, there is excessive movement of boats and people, particularly at Ocean Road which is located at the mouth of Dar es Salaam harbour. In addition, at Kunduchi, there is considerable fishing activity, including beach seining which is very destructive since it scrapes the surface of the substratum, lifting up seagrasses and associated organisms (Wagner, 1998). An additional negative impact at Ocean Road is the disposal of domestic and industrial wastes (Mashauri and Mayo, 1989; Machiwa, 1992).

A natural factor to consider is exposure to wave action. Kunduchi is the most exposed shore of the four. The greater exposure causes instability of the substratum, and the continual movement of sand leads to abrasion; thus making it difficult for many organisms to live there (Moore, 1958; Nybakken, 1982).

Mjimwema/Kendwa had the highest species diversity and biomass of fauna and also high density. This is mainly due to the fact that Mjimwema/Kendwa never dries, even at low spring tides, and is therefore protected from desiccation. There are relatively fewer anthropogenic effects than the other shores discussed. Beach seining is done in
surrounding areas, but the shape of the shoreline makes it such that the portion between Mjimwema and Kendwa is unsuitable for such an activity. Thus, its seagrass beds are relatively intact and associated organisms, particularly gastropods, are for the most part undisturbed.

Mtoni is under environmental stress due to desiccation during low tides, low percent pore water and the presence of a thick hydrogen sulphide layer. Therefore, it had the lowest species diversity. However, the few species that are adapted to that environment were found at very high densities. *Arcuatula arcuatula* had the highest density, followed by *Modiolus* sp. Since these organisms are small in size, biomass at Mtoni was low. The high density of these species, both of which are sedentary filter feeders, is probably due to the fact that there is adequate (but not vigorous) water movement in the estuary due to tides and flow of the creek. Polychaetes were also more abundant at Mtoni than on the other shores, probably since its muddy substratum has the highest organic matter content. Organic matter in the runoff from the surrounding catchment area is deposited there. Another source of organic matter is the nearby mangrove forests.

At Mtoni, the dominant organisms, i.e. *Arcuatula arcuatula* and *Modiolus* sp., were found in the greatest abundance in the middle of the shore. Both of these organisms are within the group of bivalves commonly known as mussels. It is well known that mussels generally occupy the midshore region of the intertidal zone, whether in temperate or tropical areas (Moore, 1958; Sumich, 1976; Nybakken, 1982). Mwaiseje (1973) found *Modiolus* sp. in the lower midlittoral zone at Kunduchi and Ocean Road, though it was not observed on those shores in this study.

On all shores, crabs dominated the supralittoral fringe and the upper midlittoral zone which together form the steep sandy slope. This is a common trend, particularly in the tropics where these zones are often dominated by *Ocypode* spp. (Eltringham, 1971; Sumich, 1976). The findings of this study are somewhat different from those of Mwaiseje (1973) who found the steep sandy slope to be dominated by *Ocypode* spp. In this study, while *Ocypode* spp. were numerous, the dominant organism on the steep sandy slope was *Dolita fenestrata* which Mwaiseje (1973) found only in the lower midlittoral zone. The bivalve *Donax faba* was common on the steep sandy slope in both studies.

Echinoderms such as sea urchins, sea cucumbers and starfish were common in tidal pools at Kunduchi and Ocean Road and throughout the midshore section of Mjimwema/Kendwa, which never drains, since these organisms avoid long hours of exposure to air (Moore, 1958; Sumich, 1976).

**Intertidal ecology and coastal management issues**

The coastal areas are centres for economic growth in most of the countries in the East African region. Migration towards the coast and population growth, together with overuse of resources and widespread poverty, contribute to the degradation of coastal
environments (Moffat et al., 1998). In recent years, increasing populations along the East African coast have resulted in habitat destruction and loss of biodiversity (Mgaya, 1998; Semesi et al., 1998).

Unfortunately, most coastal management projects in eastern Africa still focus on the conservation of biodiversity, often to the neglect of local community development (Moffat and Kyewalyanga, 1998). Such projects aim to protect specific species and habitats. Frequently, they try to keep the local human population away from the management site, but with, at best, short term success. On the contrary, good management should try to involve the local communities to protect their own environment while at the same time making use of its natural resources on a sustainable basis. Thus, environmental conservation and human development should go hand in hand, rather than being opposed to one another.

Proper management of the coastal zone requires the intensification of studies (Semesi et al., 1998) to get accurate information about both environmental and socio-economic aspects. On the environmental side, there must be knowledge about abiotic factors, species composition, species diversity and the distribution and abundance of species at different vertical zones and in different seasons. At the same time, in order for such research to be useful, researchers must communicate their findings to managers and policy makers who should, in turn, implement necessary actions for conservation.

In particular, more studies should be conducted concerning molluscs and sea cucumbers since, amongst the intertidal fauna, these groups are of special economic importance (Mgaya et al., 1999). More needs to be known about their distribution, ecology, reproduction and possible aquaculture techniques. We need to know which species require protection and which reproduce rapidly enough to be harvested. Sea cucumber and shell trade, if managed on a sustainable yield basis, could provide a valuable source of income to coastal communities of Tanzania (Semesi et al., 1998).

Though perhaps not of economic importance, the bivalve *Arcuatula arcuatula*, which is found in such vast numbers at Mtoni, should be investigated. A recent study reported that this bivalve constitutes a major diet item for the swimming crab *Portunus pelagicus* (Chande, 1999). There is no information about this bivalve and a study of its biology could provide useful information which may be relevant to the study of economically important bivalves. Further study of specific aspects of intertidal ecology may provide very important information which could help in the development of coastal management strategies.

As immediate measures to protect the intertidal shores of Dar es Salaam, it is recommended that the law prohibiting the destructive beach seining fishing technique should be enforced; that there should be better management of beach tourism; and that the sewage system of Dar es Salaam should be completely upgraded so as to reduce the pollution load being dumped along the coast.
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Progress of the taxonomic research on the macroalgae (Chlorophyta, Phaeophyta and Rhodophyta) along the East African coast

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ABSTRACT

This paper discusses the phycological research and gives a historical overview of papers dealing with macroalgae from the East African coast. A review of the recent progress towards a marine algal flora of the region is presented. Additionally a limited number of taxonomic problems are discussed, with emphasis on examples from Tanzania and Zanzibar. Problems comprise generic, specific and subspecific distinctions, perpetuation of wrong identifications from 'reference works', and checklists with doubtful identifications that lack voucher specimens. Finally a list of 91 new species for Kenya (23), Tanzania (24), the East African coast (26) and the Indian Ocean (18) is added.

HISTORY

The earliest records of algae from the East African coast were largely made by German phycologists, who generally depended on collections from amateur botanists or European citizens living in Africa. Sonder (1879) was the first to report a relatively large number of seaweed species (40 spp.) from Zanzibar, collected by Dr A. Roscher. The genus Roschera (a taxonomic synonym for Tolypiocladia) was erected to honour Roscher. Schmitz (1895) listed 68 species of red algae from Tanzania and Kenya.

In the first half of the 20th century relatively few supplementary species were added by a variety of authors. In the second half of that century there was a renewed interest in phycology along the East African coast. Interesting papers were published by Gerloff (1957) on algae from Dar es Salaam and by Schmidt (1957) providing more general information on the marine vegetation along the East African coast. Taylor gave accounts on Turbinaria (1966), including the description of T. crateriformis Taylor and T. kenyensis Taylor, both from the Kenyan coast, and on Caulerpa (1967) from the Tanzanian and Kenyan coasts. Important progress in Tanzanian phycology was made by Jaasund (1969, 1970a–c, 1976, 1977a–d), who provided both annotated lists of Chloro-, Phaeo- and Rhodophyta, and more importantly a 'Field Guide for the Seaweeds
of Tanzania’ (including 291 taxa). The latter at present is the only algal identification work for the East African coast. A set of the Jaasund herbarium is housed at the University of Dar es Salaam (DSM), additional collections are housed in Göteborg (GB) and the Natural History Museum, London (BM). Mshigeni and Chapman (1994) also published an important series of articles on seaweeds: several on Eucheuma (Mshigeni 1973), Hypnea (Mshigeni and Chapman, 1994) and other economically important genera such as Sargassum (Mshigeni and Chapman, 1987); other papers are on life histories of specific species.

In the last 40 years a series of authors mentioned a few seaweeds from Kenya. Gerloff (1960) reported 36 taxa of which 23 were new for that region. Isaac’s publications (1967, 1968, 1971), based on his own seaweed collections from the Kenyan coast, are an important contribution to the knowledge of the African coast. The specimens are housed in the herbarium of the National Museums of Kenya in Nairobi (EA).

Whereas the Kenyan and Tanzanian coasts were relatively well studied from a phycological point of view, data on algae from Somalia and Mozambique are scarce. Hauck (1886–1889, 1888) wrote the first account on the algae from Somalia collected by Hildebrandt, describing new records for the region. Later, a few authors added some species and Sacco (1965) reported 20 taxa not previously known from the northern part of that country. Finally Sartoni (1975, 1976, 1978, 1979, 1986, 1992) listed 69 species of green, brown and red algae from the southern part of Somalia.

Except for the Inhaca Island region, marine algae of Mozambique have been less studied, most of the limited publications being from the second half of the 20th century. Isaac (1956, 1957, 1958, 1959) and Isaac and Chamberlain (1958) published a series of papers on the algal flora of Inhaca Island; Pocock (1958) listed 33 taxa from this coast and Critchley et al. (1997) provided an updated species list from that area with 205 taxa, many of which, however, are not identified to species level.

The species of macroalgae mentioned from the entire East African coast were listed by Lawson (1980). This list, however, contains a number of taxa under different synonyms. The publication of the ‘Catalogue of Benthic Marine Algae of the Indian Ocean’ by Silva et al. (1996) has greatly facilitated the process of checking correct nomenclature, including synonyms. It also mentions the biogeographical distribution of each taxon, although this information has to be used with care as identifications have not been checked but were taken from published data.

Since 1980 the phycology department of the University of Ghent has been carrying out taxonomic, autecological and biogeographical research of macroalgae in the tropical part of the Indo-SW Pacific, with emphasis on the area around Papua New Guinea/Indonesia. From 1985 onwards Kenya and Tanzania were also included, with supplementary collections around the Seychelles, Socotra, Réunion, Mauritius, the Maldives and Sri Lanka. The collections from the East African coast, of which duplicate specimens have been deposited at the Kenya Marine and Fisheries Institute (Mombasa, Kenya) and the Institute of Marine Sciences (Zanzibar, Tanzania) are largely being
studied within the framework of MSc theses. To date the number of published results is still limited. These include papers on the genus *Caulerpa* (Coppejans and Beeckman, 1989, 1990), the family Codiales (Van den Heede and Coppejans, 1995; Coppejans and Van den Heede, 1996), macroalgae associated with mangroves (Coppejans and Gallin, 1989; De Schryver, 1990) and with seagrasses (Coppejans et al., 1992; Leliaert et al., 2000), and a chapter on seaweeds (Coppejans et al., 1997) in 'A Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands'.

Annotated checklists of Chlorophyta, Phaeophyta and Rhodophyta for the East African coast, including the citation of voucher specimens are being prepared. The results have not been published as yet due to the numerous taxonomic problems in many groups, not wanting to perpetuate erroneous identifications. A list of new records for the E. African coast has been compiled (Coppejans et al., 2000).

**MAJOR TAXONOMIC PROBLEMS ENCOUNTERED**

**Varying classification systems**

Due to ongoing macro-morphological, anatomical, ultrastructural and molecular research, new orders have recently been created, especially within the Rhodophyta (Saunders and Kraft, 1996). Some orders appear to have been merged, such as the Cladophorales and Siphonocladales (Chlorophyta) (van den Hoek, 1982; Olsen-Stojkovich, 1986; Bakker et al., 1994), neither of these orders being monophyletic; while still others (e.g. Cryptonemiales, Rhodophyta) have been abandoned (Kraft and Robins, 1985). The rough comparison of species lists, using different classification systems, can therefore be tricky.

**Problems with generic distinction**

Within the Cladophorales-Siphonocladales complex the genera *Boodlea* and *Phyllodictyon* are difficult to separate because of the lack of distinct taxonomic characters and their considerable morphological plasticity. *Phyllodictyon*, recently split off from the genus *Struwea* (Kraft and Wynne, 1996), is characterised by netlike stipitate blades in young specimens. In older, well-developed thalli of, e.g. *P. anastomosans* (Harvey) Kraft and Wynne the stipe becomes less conspicuous, resulting in a similar habit to *Boodlea montagnei* (Harvey ex J. Gray) Egerod, which is also characterised by bladelets of oppositely branched filaments. Culture experiments are in progress to determine whether *Boodlea* and *Phyllodictyon* should be regarded as one genus. Recent life history and molecular evidence seem to support this hypothesis (Bodenbender and Schnetter, 1990; Kooistra et al., 1993).

The status of the genera *Cladophora* (polyphyletic according to Bakker et al., 1994), *Cladophoropsis* and *Struveopsis* still have to be elucidated. *Cladophoropsis* only differs from some *Cladophora* species (of the section Repentes) by the postponement of cross wall formation at the insertion point of a lateral. According to van den Hoek
(1982) this may also occur in some Cladophora species, albeit to a lesser degree. Rhyne and Robinson (1968) have also observed this phenomenon for some species of Struveopsis. The latter differs from both Cladophora and Cladophoropsis by the formation of distinct blade-like structures. A comparison of previous records of the Siphoncladales-Cladophorales complex with the collection in Ghent is given in Table 1.

Problems with specific distinction

In the past, variability of morphological and anatomical characters induced by ecological or biogeographical factors has been underestimated. The lack of morphometric comparisons with the existing species have led to the description of numerous ‘new species’, only differing in a single (variable) character. Recent monographic studies have therefore frequently led to the synonymisation of several species. Børgesen (1940, 1946, 1948, 1952), for example, mentions 9 species of Dictyosphaeria (Chlorophyta) from Mauritius, of which 3 are new species. The distinction between these species is based on the morphology of the trabeculae in the cells. As this character apparently is highly variable, some of these species most probably will have to be synonymised. In the genus Valonia (Chlorophyta) cell morphology and dimensions, as well as the placement of the tenaculae are discriminative characters, but each of them is variable within a wide range. Already half of the 30 described species have been reduced to synonymy (Olsen and West, 1988).

A recent monographic study of the genus Dictyota in the Indian Ocean (De Clerck, 1999) was based on a morphometric approach, including 75 vegetative and 26 reproductive characters, combined with genetic analysis. It resulted in reducing the total number of Dictyota species from the Indian Ocean from 42 to 23 (including 2 newly described species). Jaasund (1970c) published a detailed account of the genus from the Tanzanian coast, including 9 species. De Clerck’s study (1999) included Jaasund’s collections housed in the Herbarium of Dar es Salaam (DSM) and the Natural History Museum London (BM) as well as numerous collections by Coppejans and co-workers. He recognised 12 species for the Tanzanian coastline of which only one mentioned by Jaasund (D. ciliolata Sonder ex Kützing) remains without nomenclatural or taxonomic changes (Table 2). Some species concepts of Jaasund were too narrow, e.g. the recurved branches of D. pardalis Kützing proved to be ecologically induced. Specimens from wave-swept environments tend to form branchlets that offer additional holdfasts while these were absent from plants growing in sheltered lagoons and intertidal pools (and identified as D. cervicornis Kützing). All intermediates between both growth forms occur and therefore both entities have been merged.

Another genus where species definition is not always clear cut, at least in some sections, is the genus Caulerpa. Silva et al. (1996) still distinguish C. peltata Lamouroux as a separate species even though Ohba and Enomoto (1987) induced this growth form in culture experiments from C. racemosa (Forsskål) J. Agardh var. laetevirens (Montagne) Weber-van Bosse. As a result a number of authors (Coppejans and Beeckman, 1989;
Table 1. Comparison of previous records of the Siphonocladales-Cladophorales complex with the collections in Ghent

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<td><strong>Cladophora prolifera</strong> (Rothpletz) Kützing</td>
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<td><strong>Cladophora patentiramea</strong> (Montagne) Kützing f. longiarticulata Reinbold</td>
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<td><strong>Cladophora vagabunda</strong> (Linn.) van den Hoek</td>
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Table 1 continued

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<th>Isaac (1967, 1971); Moorjani and Simpson (1988)</th>
<th>Ghent collections</th>
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<td><em>Rhizoclonium grande</em> Børgesen</td>
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<td>Chamaedoris auriculata Børgesen</td>
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<td><strong>Microdictyon japonicum</strong> Setchell</td>
<td>new genus for Tanzania</td>
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<td><strong>Struva anastomosans</strong> (Harvey) Piccone &amp; Grunow ex Piccone</td>
<td><strong>Phyllodictyon anastomosans</strong> (Harvey) Kraft &amp; Wynne</td>
<td>new record Tanzania</td>
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<td>new record Tanzania</td>
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<td><strong>Spongocladia vaucheriaeformis</strong> Areschoug</td>
<td><strong>Spongocladia vaucheriaeformis</strong> Areschoug</td>
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<td><strong>Struva ramosa</strong> Dickie</td>
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<td><em>Valonia fastigiata</em> Harvey</td>
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<td><em>Valonia macrophysa</em> Kützing</td>
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<td><em>Valonia utricularis</em> (Roth) C. Agardh</td>
<td>new record for Tanzania</td>
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<td><em>Valoniopsis pachynema</em> (G. Martens) Børgesen</td>
<td><em>Valoniopsis pachynema</em> (G. Martens) Børgesen</td>
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<td><em>Valonia ventricosa</em> J. Agardh</td>
<td><em>Valonia ventricosa</em> J. Agardh</td>
<td><em>Valonia ventricosa</em> J. Agardh Olsen &amp; J. West</td>
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<tr>
<td>Total</td>
<td>22 species</td>
<td>27 species</td>
<td>29 species</td>
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Coppejans, 1992; Prud’homme van Reine et al., 1996) have reduced this entity to variety level or even to growth form (ecd). The genus *Sargassum* is the textbook example of extreme morphological variability. As stated by Kilari et al. (1992) the causes of variability are numerous: position of ‘bladelts’ and air vesicles on the plant (basal parts different from apical ones), sexual dimorphism, seasonality, environmental factors, random phenotypic expression and geographically correlated genotypic differences. Monographic studies using modern techniques (biometrics, culture experiments, outplanting and transplanting, experimental hybridisation, chemotaxonomy, molecular taxonomy) have only recently started. The number of species reported from different regions will therefore most probably be drastically reduced.

A relatively recent problem concerns convergent evolution, i.e. the presence of morphologically and anatomically similar species in different oceans that are genetically distinct, having evolved independently from one another. *Halimeda discoidea* Decaisne is recorded from the Atlantic, the Pacific and the Indian Oceans. Genetic analysis of Atlantic and Pacific specimens from Panama by Kooistra (pers. commun.) shows that both entities are markedly different, although they are morphometrically almost indistinguishable. A supplementary problem is that some growth forms of *H. discoidea* in some parts of the Indian Ocean are difficult to tell apart from *H. tuna* (Ellis and Solander) Lamouroux. Specimens of both species are now being collected from the same sites on Zanzibar and preserved in ethanol for genetic analysis by Kooistra. It is
Table 2. Comparison of *Dictyota* species listed in Jaasund (1970c) and De Clerck (1999)

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<td><em>D. adnata</em> sensu Weber-van Bosse</td>
<td><em>D. humifusa</em> Hönnig, Schnetter &amp; Coppejans</td>
<td>Coppejans (1990) and Hönnig et al. (1992a)</td>
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<td><em>(D. friabilis</em> Setchell</td>
<td><em>D. cervicornis</em> Kützing</td>
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<td><em>(D. cervicornis</em> Kützing</td>
<td><em>D. ciliolata</em> Sonder ex Kützing</td>
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<tr>
<td><em>(D. ciliolata</em> Sonder ex Kützing</td>
<td><em>D. ceylanica</em> Kützing</td>
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<tr>
<td><em>(D. divaricata</em> Lamouroux</td>
<td><em>D. bartayresiana</em> Lamouroux</td>
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<tr>
<td><em>(D. divaricata</em> Lamouroux</td>
<td><em>D. adnata</em> Zanardini</td>
<td>Coppejans (1990) new species</td>
</tr>
<tr>
<td><em>(D. ceylanica</em> Kützing</td>
<td><em>D. friabilis</em> Setchell</td>
<td>new for the East African coast</td>
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<tr>
<td><em>(D. dichotoma</em> (Hudson) Lamouroux</td>
<td><em>D. hamifera</em> Setchell</td>
<td>new for the Indian Ocean</td>
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<td></td>
<td><em>(D. stolonifera</em> Dawson</td>
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<td></td>
<td><em>(D. rigid</em> De Clerck &amp; Coppejans</td>
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<td><em>(D. grossedentata</em> De Clerck</td>
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<td>&amp; Coppejans</td>
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9 species 12 species

not clear yet what the taxonomic status is of entities that are morphometrically indistinguishable but which appear to be genetically different.

Problems with subspecific distinction

In some genera (e.g. *Caulerpa*) numerous varieties and forms have been described. If one examines large collections from different regions, continuous series can be made between the ‘typical’ varieties making the attribution of isolated specimens to a given subspecific entity subjective. As with *Sargassum* species, transplantation and culture experiments of *Caulerpa* should be carried out. Olsen et al. (1998) and Jousson et al. (1998) are at present conducting genetic analysis on representatives of this genus.

Perpetual wrong identifications from ‘reference works’

Jaasund (1970c, 1976) mentions *D. bartayresiana* sensu Vickers (as *D. bartayresii*) and *D. friabilis* Setchell from Tanzania. De Clerck (1999) studied the type specimens of both *D. bartayresiana* and *D. friabilis* as well as Jaasund’s material identified as such. Both were misidentified by Jaasund and have therefore resulted in erroneous species descriptions, which have been used subsequently. Both entities belong to the ecologically induced erect and prostrate growth forms of *D. crispata* Lamouroux respectively. The ‘real’ *D. bartayresiana* is also present along the Tanzanian coast, but was identified as
*D. dichotoma* (Hudson) Lamouroux by Jaasund. Another example is the entity described by Jaasund (1976) as *D. adnata* sensu Weber-van Bosse. Coppejans (1990) and Hörnig et al. (1992a) proved that this entity was the newly described *D. humifusa* Hörnig, Schnetter and Coppejans, a sublittoral, mostly epiphytic, strongly iridescent species with sporangia scattered over its surface. The 'real' *D. adnata* Zanardini was discovered in Tanzania in the upper intertidal zone, between knee roots and pneumatophores of mangrove trees (or in the Bostrychietum of vertical cliff walls), and is dull dark brown with typical marginal sori. Similar errors in other genera have also been found in other field guides, especially in some recent, nice-looking and easy to use photographic booklets where taxonomic correctness has been subordinated to the beauty of the underwater pictures.

**Checklists without reference specimens or with doubtful identifications**

During the identification of our collections from the Indian Ocean we also checked specimens of previous collectors in that area, in as far as these are traceable (voucher specimens are rarely mentioned in checklists). The number of misidentifications, especially for some regions, is alarming, hampering biogeographical studies.

**Publications including synonymised species**

Some publications include the same taxon under two or even three different names, e.g. Lawson (1980) where *Chlorodesmis fastigiata* (C. Agardh) Ducker is also mentioned under *Avrainvillea comosa* (Bailey and Harvey) Murray and Boodle, or *Avrainvillea obscura* J. Agardh also under its synonym *A. capituliformis* Tanaka, etc. In the same publication *Dictyota radicans* Harvey is cited from Kenya after Lind (1956), but she only mentions an unidentified *Dictyota* sp. Rough counts of number of species (biodiversity studies) from such works are as a result biased. Since Silva et al.'s (1996) *magnum opus* this problem can easily be resolved.

**RESULTS**

Phycological research at the University of Ghent is mainly carried out on taxonomic groups, but ecological topics are also studied. The zonation of seagrasses and the associated algae in Gazi Bay (Kenya) were examined by De Wit (1988) and Coppejans et al. (1992); De Pauw (1990) examined the vegetation of a tidal creek in Gazi Bay; De Schryver (1990) worked on the epiphytes of mangroves (Bostrychietum) in Gazi Bay; Provoost (1992) studied the zonation of intertidal vegetation of Iwatine Bay (Mombasa, Kenya); and Vanreusel et al. (2000) examined the macroalgal epiphytes on seagrasses in Zanzibar. Taxonomic groups being studied include:

**Chlorophyta**

The family Caulerpaceae (*Avrainvillea, Boodleopsis, Caulerpa, Chlorodesmis, Rhipidosiphon, Rhipila, Rhipiliopsis, Tydemania, Udotea*) by Coppejans and Beeckman
(1989, 1990); the genus *Caulerpa* is presently being researched in collaboration with de Senerpont Domis (Rijksherbarium Leiden, Netherlands) examining the morphometric part, while Olsen’s team (Rijksuniversiteit Groningen, Netherlands) is performing the genetic analysis. The families Bryopsidaceae (*Bryopsis, Trichosolen*) and Codiaeaceae (*Codium*) have been studied by Van den Heede (1994), Coppejans and Van den Heede (1996) and Van den Heede and Coppejans (1995). The family Halimedaceae was preliminarily studied by Verellen (1990). The genus *Halimeda* is now being studied monographically on a worldwide scale by O. Dargent (1998), Dargent and Coppejans (1998) using morphometrics, in collaboration with W. Kooistra from the Smithsonian Institute, Panama, examining material from a genetic perspective. As stated above, the genus *Halimeda* is problematic: the same morphospecies appear to have evolved several times in different oceans. Although their morphology and anatomy appear to be extremely similar, their genetic information separates them into different clades. The Cladophorales/Siphonocladales complex was preliminarily studied by Vackier (1993) and Verstraete (1993) and is now being worked out in detail by F. Leliaert (Leliaert et al., 1997) (Table 1).

The Ulvales are generally identified with monographs on European representatives (Bliding, 1963, 1969). A worldwide revision (including genetic analysis) is imperative to ascertain whether tropical representatives are identical to the temperate species.

**Phaeophyta**

Within the order Dictyotales, as stated above in the section on taxonomic problems, the descriptions of most *Dictyota* species from the Indian Ocean were redefined by De Clerck (1999), after study of the respective type specimens. A detailed comparison between Jaasund’s account on the genus and the recent revision by De Clerck (1999) is presented in Table 2.

Other genera of the Dictyotales have been studied by Leuci (1995), De Smet (2000) and Muylle (2000). In the genus, *Padina* some specimens have been found to have intermediate characters between described species. The variability of anatomical characters therefore should be studied in more detail.

In the order Fucales the genus *Sargassum* is extremely troublesome: our specimens have tentatively been identified following Jaasund (1976), but it is clear that there are more entities than are mentioned in his field guide.

**Rhodophyta**

The study of ‘difficult groups’ within the red algae has only recently been started in collaboration with A. Millar, G. Kraft, J. Huismman (order Nemaliales), M. Wynne (order Ceramiales) and L. Liao (order Gracilariales). Therefore the results on this group are preliminary, but new species and even new genera for the East African coast have been collected.
DISCUSSION

Regional checklists are useful tools in for example, biogeographical studies, but the correctness of the identifications in these works is not always guaranteed. The use of misapplied names, and thus the presence of erroneous species descriptions in field guides may have compounding negative effect in that they perpetuate wrong species concepts. The Southeast Asian Phycology working group therefore decided that the seaweed database for that region would only comprise data that includes voucher specimens. This would allow the identifications from different regions by a specialist in each group.

The need for a seaweed flora for the East African coast, similar to Lawson and John’s (1987) for the West African coast or to Stegenga et al.’s (1997) South African coast, is an absolute necessity. Numerous groups are being studied at the University of Ghent, mostly in collaboration with taxonomic specialists from around the world. Large collections from diverse biotopes (mangrove areas, seagrass beds, vertical cliff walls, tide channels and pools, lagoons, reef platforms, seaward slopes of reefs) are already available, allowing the study of in situ variability of morphological and anatomical characters. Subtidal collections are still underrepresented because of the general inaccessibility of scuba infrastructure. This habitat contains the largest number of new species still to be discovered.

This paper mentions 91 new records for the area (Table 3), of which 18 are new for the Indian Ocean, 26 are new for the East African coast and 47 are new for either Kenya (23) or Tanzania (24).

In as far as is possible specimens from the African coast are compared with material collected from other regions of the Indian Ocean viz. the Seychelles, the Comores, Mauritius, Socotra, Sri Lanka, Indonesia and Papua New Guinea (SW Pacific).

Large stretches of the Mozambican and Somalian coasts (especially the northern part of both countries) are still under-sampled. Corallines and Sargassum have only been sporadically collected and studied. Their identification is a specialisation in itself.

Whereas previous collecting was restricted to herbarium-pressed and formalin preserved specimens, the present collection of living material (for culture experiments on morphological plasticity) and of silica gel-dried or alcohol-preserved samples (for genetic analysis) are also needed, for some recalcitrant groups. The study of type specimens is indispensable for the correct redescription of some species: original descriptions are frequently extremely concise and hardly diagnostic. As has been illustrated with De Clerck’s monograph on Indian Ocean Dictyota, species studies should include the examination of type specimens, large collections, morphometric analysis and wherever possible, genetic analysis. Such studies result in the synonymisation of some species and a clear description of new species.
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Enhancing environmental awareness through marine education

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Department of Biology
Memorial University of Newfoundland, St John's, Newfoundland, Canada A1 B3X5

INTRODUCTION

Throughout this colloquium reference has been made to a number of environmental problems, most of them due to human activities (e.g. clearing mangrove forests, dynamite fishing, sewage pollution, etc.). While attempts are being made to correct these problems through new legislation and educating adults in more environmentally friendly practices, it is my thesis that we should be putting much more effort into the environmental education of young, school-age children since such efforts will, in the long run, have the greater impact on environmental awareness.

AIMS OF ENVIRONMENTAL EDUCATION

According to Stapp et al. (1969) "Environmental education is aimed at producing citizens:
1. knowledgeable concerning their biophysical environment and its associated problems;
2. aware of how to help solve these problems; and
3. motivated to work toward their solution."

Environmental education, whether in the formal education setting (schools, colleges, universities) or in the informal setting (organisations, media, etc.), seeks to produce individuals with positive attitudes and values about their environment.

ADOPTION OF NEW IDEAS AND PRACTICES

The research suggests that the adoption and implementation of new ideas and practices involves a number of different stages, namely awareness, interest, evaluation, trial and adoption (Rogers, 1962).
1. Awareness: The individual is exposed to a new idea or practice but lacks information about it.
2. Interest (or information): The individual becomes interested in the new idea or practice and seeks information about it.
3. Evaluation (or application): The individual mentally applies the idea or practice to his/her present and anticipated future situation and then decides whether or not to try it.
4. Trial: The individual uses the new idea or practice on a small scale in order to determine its utility in his or her own situation.

5. Adoption: The individual decides to continue full use of the new idea or practice.

It is clear then that the adoption of new ideas and practices is not something that can be done quickly — the process takes time. Of course many people will never actually adopt the new idea or practice. The research on adoption of new ideas and practices is primarily concerned with changing the practices of adults who have a direct impact on the environment through their work (i.e. fishers, wood cutters, etc.).

ENVIRONMENTAL EDUCATION RESEARCH FINDINGS

Reviews of the literature from the field of environmental education have produced the following important conclusions:

1. Most attitudes are formed prior to secondary school; there is little change after that.

2. Even children of kindergarten age can form affective concepts (that is attitudes and values) regarding environmental issues.

3. While knowledge gained is often lost over time, attitudes and values remain, and often improve.

4. The media, particularly television, are powerful sources for influencing attitudes and values.

CONCLUSIONS FROM ENVIRONMENTAL EDUCATION

While it is important to target adults as they are the ones having the greatest impact on the environment, it is important to recognise that the adoption of new practices can take a very long time. In addition, the evidence suggests that adults are less likely to change their attitudes to the environment than are young primary school-age children. I strongly believe that a greater effort should be made at introducing environmental education into the primary grades, as has been done in Zanzibar schools. This will have the greatest impact in the long term since there is the opportunity to affect positive environmental attitudes in the school children which will last into adulthood.

RECOMMENDATIONS

Formal education
- Incorporate environmental education into the primary school curriculum, concentrating on the affective domain (i.e. attitudes and values).
- Emphasise hands-on activities and outdoor experiences.
- Emphasise the cognitive aspects (i.e. concepts and knowledge) of environmental education in secondary school.
Examples of University of Dar es Salaam/Memorial University materials developed for schools:
(a) Environmental education activities for Zanzibar primary schools — Standards I to III, 1996;
(b) Zanzibar environment education workshop — Principles and methods of science and environmental education, 1997.

Informal education
- Printed materials (books, brochures etc.); Displays (bulletin boards, charts etc.); Videos (VCRs, television). Examples: University of Dar es Salaam/Memorial University materials.

Publications
Examples include:
(a) 'An introduction to the coastal ecosystems of Zanzibar'. J. Shunula & A. Whittick, 1997;
(b) 'The mangroves of Zanzibar'. J. Shunula & A. Whittick, 1996.

Videos
Examples:
(a) 'Mangrove forests: resources for all generations'
(b) 'Beach erosion'
(c) 'The garden of the sea: The coral reef'
(d) 'Simple field activities in environmental education'.

FUTURE POSSIBILITIES
With the lack of local resources (money, personnel, equipment, etc.), and the increasing use of the Internet, there is the possibility of developing materials on a regional basis, particularly at the secondary school/college/university level, e.g.:
- Correspondence courses (i.e. Memorial University's Biology 2041 'Environmental Science'.
- CD-ROM based materials (i.e. Biodiversity Identification Guides).
- Web-based courses (i.e. Memorial University's Biology 2041 'Environmental Science' —under development).
- Virtual Universities (i.e. University of the West Indian Ocean).

REFERENCES
Support communications programmes: Vital links in sustainable resource management (A bridge between science and action)

P.G. MacLeod

Anigraph Productions Limited, St John's, Newfoundland, Canada

INTRODUCTION

Consideration of support communications is appropriate at a conference concerned with advances in Marine Science in Tanzania. Certainly, to create an effective resource management system, there must be good science. However to make that system sustainable, there must be political will backed by informed public support. For this, the issues must be understood by all stakeholders, planners and policy makers, including politicians, as well as by the public at large. Furthermore, everyone must be motivated to address the issues in a positive way. It is in the facilitation of this that support communication programmes can provide a vital link and perform an essential service.

Rather than providing a theoretical or abstract discourse on Development Support Communications, this paper will briefly outline what the CIDA-funded Memorial University of Newfoundland–University of Dar es Salaam Linkage Project has tried to do at IMS over the past decade, to establish outreach capacity based on support communication activities. This component of the Project, imperfect though it may sometimes have been, has demonstrated that activities of this type can be a vital link in sustainable resource management. As IMS moves into the 21st century, it will hopefully be possible to build on the communication activities of recent years, to strengthen the role of this institution in the country and in the region.

OBJECTIVES

This Linkage Project began a decade ago, with an inception mission on which it was discovered that there was a shared belief with Dr Ngoile, who was then Director of IMS, that science must serve the community, the nation and the region. Memorial University had pioneered the use of media tools in participatory development work, so it was only natural to design into the project, a communications component to support the development of outreach capacity at IMS.

In the broadest terms, the objectives of the support communications component were:
- to help all users of and stakeholders in the marine resources of the region better understand how the coastal ecosystem works; and
to motivate and encourage those users and stakeholders to learn how to protect the environment and to sustain the resources upon which they depend for their very existence.

This type of input can facilitate the creation of a positive and enabling environment within which planners can plan, and decision-makers can implement sustainable resource management programmes. Thus from the very beginning, the project placed itself in the role of providing an interface between scientists on the one hand, and the community—in the broadest sense of that word—on the other.

Of course communications tools can help to inform, to teach and to motivate many who might otherwise never be reached. However there is much more to using media tools than simply imposing messages from the top, down. The process of using media as a participatory research tool can help researchers access the traditional knowledge of resource users such as fishermen, and help those users share their experience and knowledge with scientists. This important use of media is too often overlooked. Furthermore, creatively used, communication tools can sensitise scientists to social, economic and cultural factors that must be taken into consideration if an environmental management system is to be effective.

When Dr Francis became Director of IMS, he brought the same commitment to the Institute's outreach mission to contribute to the development of sound environmental policies, and to socioeconomic development in the country and the region. This was important, for it ensured programme continuity.

ACHIEVEMENTS

Seldom do support communications programmes achieve all their objectives in the way their designers anticipate. What has occurred at IMS is not an exception. But it has demonstrated that it is possible to utilise support media to create a functional communication bridge between scientists and the public, and between scientists and those who must create and implement policies for sustainable development. This can be illustrated by some specific examples of translating scientific research into practical, action-oriented communications tools.

One of the first video productions of IMS looked at mangrove forest degradation. It was a collaboration between the production team and Dr Jude Shunula. The video presented scientific information based on his research and explained the important position mangrove forests occupy in the ecosystem. But it went further and addressed the very serious problem of over-cutting that threatens the forests. In addition to the voice of the scientist, voices of actual cutters and managers of the resource were heard discussing this critical issue. Screenings of that video in communities with mangrove cutters, and with government officers responsible for managing the resource, contributed to the development of practices that helped reduce some of the pressure on the resource.
Another early activity was a participatory development project with women in Paje, then in the early stages of developing seaweed farming. The process of working with video helped Ms Flower Msuya and other university researchers who were studying the seaweeds, better understand the social and economic dynamics of this new community-based industry. The final video helped the women farmers understand more about the marine resource they were cultivating and about the industry itself. The process was beneficial to everyone who participated.

Several programmes produced in collaboration with the Zanzibar Department of the Environment dealt with local pollution issues, and with the need to protect the coral reefs. These programmes have been widely screened to good effect with residents of the islands as well as with many of the visitors who come here as tourists. They are helping sensitise thousands to marine environmental issues.

Two programmes focused on the issue of beach erosion and its potentially disastrous implications. The first, sponsored by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and produced in collaboration with the Kenya Marine Fisheries Research Institute in Mombasa, was used effectively as a theme programme for an important regional conference. It was also designed to be incorporated into IOC's web site. The second, based on research by Dr Francis, Dr Nyandwi and Flower Msuya, was funded by UNESCO’s Nairobi office, which recognises the importance of using different types of support communications programmes to disseminate information about research being done in this region on marine issues. In addition to the importance of the content itself, both of these productions demonstrated the value of forming development partnerships with international organisations.

Two videos developed by Narriman Jiddawi look at the important role women play in the fishery of Zanzibar. These programmes have made a significant contribution to understanding and legitimising women’s roles in what is essentially a male-dominated activity in a very conservative society. Support communications programmes of this type are important in helping women start to recognise that they are crucial partners in managing the marine resources.

An innovative drama, initiated by Dr Ron Johnson and made with Swedish project funding, is helping school children understand important concepts about the marine environment that surrounds them, and the need to protect it. This video has been shown in many countries presenting coastal zone issues in ways that children can relate to, and it will continue to be a very important tool for educators throughout the region.

Also in the school education context, three video units show teachers how to create games that demonstrate important scientific principles. This was part of a workshop that Dr Mike Collins conducted for teachers and curriculum staff from the Zanzibar Ministry of Education. While created for use with teachers in Zanzibar, these demonstrations would be appropriate for teacher training activities anywhere.
CONTRIBUTIONS OF THE LINKAGE PROJECT

These are examples of the video programmes that have been created here at IMS. Most have English versions, but all are in Kiswahili. In fact most of them have been produced in that language and translated, because there can only be true communication if you speak to audiences in their own language. While this seems an obvious point, it is surprising how often material appears in English or French and somehow users are just expected to understand it or translate it, which can sometimes be a difficult proposition, especially when graphic elements are involved.

In addition to their primary utilisation, most of these videos have been shown on Television Zanzibar—some, numerous times. A number of them have been televised on the Tanzania mainland, and some have been shown at conferences around the world. All of them can be used for years to come in schools here, on the mainland and elsewhere in the region. In addition, many visiting students, scientists and experts routinely come to IMS to view some of the video material, as part of their orientation before going into the field.

Reviewing the list of themes and sub-themes for this conference, it is impressive to note how many over the years have been addressed, directly or indirectly, by the development communications activities of the Marine Education Extension Development (MEED) unit. It can be convincingly argued that this outreach effort, drawing on specific research from IMS scientists, has helped create a more receptive environment to implement (in the words of the conference brochure) “a more effective environmental management system.”

RECOMMENDATIONS

What has occurred to this point can only be looked on as laying a foundation on which IMS can build, if there is the will to do so, as plans are made for the 21st century. It is impossible to overestimate the importance of utilising communication tools effectively to translate science into actions that are fully supported by the public at large, by resource users, and by government planners and managers. Therefore IMS is positioned to expand its outreach, extension and distance learning activities.

However it is very important at all times to remember that media tools are means, not ends in themselves, and to avoid being seduced by them. Effectively utilised, they can help you to inform, to educate, to motivate and ultimately to mobilise positive action to implement effective, sustainable, environmental management of the marine resources that are so important to this region. This can make the difference between the success and failure of everything else you do.

When you use these tools, be cognisant of and sympathetic towards your audiences. Recognise that for the most part, the audiences you are trying to reach really are not interested in complex scientific language. How you communicate amongst yourselves is one thing. But sentences cluttered with scientific names that audiences are not going
to remember, especially in a video script or a radio programme do not display erudition. Rather they intimidate and deflect the very audiences you hope to reach. Ultimately this defeats the very purpose you are trying to achieve.

Strive for simplicity, clarity and conciseness, especially with audio-visual media. Create different pieces for different audiences. None of the great popularisers of science—Cousteau, Attenborough, Sagan, Suzuki—have spoken down to their audiences. Rather, they have treated them with respect. While you may quibble with their science, few would disagree that what they and their ilk have done to stimulate interest in this field is quite remarkable. Don’t be afraid to experiment with presentation styles. As Voltaire said: “All styles are good, except the boring”.

Development agencies, universities and other organisations who help fund the work of IMS and institutions like it should increase their investment in relevant activities that will sustain and expand the type of outreach effort that has been initiated. To do this is as valid an investment as linking peer institutions or facilitating communications between scientists. But do not look for ‘cheap’ productions.

For IMS to be able to continue to do this work, it must recover costs to maintain and replace equipment and expand its communications technology. It is sadly true that staffing costs are, by European standards, very low. But the purchase and maintenance of equipment and the acquisition of software and supplies can be significantly higher, and these costs must be built into budgets if this work is to be sustained and developed further. As well, invest in more training of production and utilisation staff. Put money into participatory media activities that create dialogue with those who fish or farm the resources you are studying. It may be the most productive, long-term investment you make.

Supporting the communications outreach work is a wonderful opportunity to communicate very important scientific findings to those who directly exploit or utilise the resources you are studying. By so doing, you not only can help them understand the issues but also provide them with essential information they need to help conserve resources and utilise them in a sustainable way.

This is not to suggest that scientists should become media producers. But with the MEED Unit here, and perhaps with similar units in other institutions, you have the opportunity to work as part of a team, providing the content that production people need to create programmes that explain your science. Scientists from other institutions may be able to work with IMS to do this and this should be encouraged where possible.

Perhaps the most important work you may do in your scientific careers will be to collaborate to find creative ways to present research so that children and young people understand it and respond in positive ways that make a difference. After all, they are the ones who will be the beneficiaries of your science. They are the ones who will accept or reject it. They are the ones who in the future must live with or survive without the more effective environmental management systems you speak of building.
ACKNOWLEDGEMENTS

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Design and preliminary results of an integrated mariculture pond system (IMPS) at Makoba, Zanzibar, Tanzania

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ABSTRACT

Mariculture development in Zanzibar Island, Tanzania, is limited by the lack of appropriate technology for local conditions and cost-effective solutions for preventing nutrient enrichment of the marine environment. An integrated mariculture pond system (IMPS) concept originally developed in Israel is considered as a possible model for mariculture development in Zanzibar. An experimental IMPS has been established near the estuary of Kiwani Creek at Makoba on the west coast of the island. Water supply is provided by a reservoir fed by tidal fluctuations in the creek. The experimental system consists of six ponds of 170m\textsuperscript{3} each, for the culture of fish, shellfish and seaweed. The ponds were stocked during June and July 1998 with 4000 fingerlings of rabbitfish (\textit{Siganus} sp.) and with different species of shellfish and seaweed. Water quality parameters in the ponds, such as temperature, oxygen and salinity, were kept within acceptable limits by a periodic water supply. Fish were fed daily with a diet developed for this project. Preliminary results indicate reasonable growth of the fish but also mortality of fish, shellfish and seaweed.

INTRODUCTION

Following the success of seaweed mariculture in Zanzibar (Msuya and Mmochi, 1995; Msuya et al., 1996), there is local interest in starting fish, shellfish and crustacean mariculture. A few rudimentary ponds already exist at Nungwi and Chwaka on Zanzibar Island and elsewhere on Pemba Island (Mmochi and Jiddawi, 1996; Mmochi et al., 1997). However, the lack of artificial feed and environmentally sustainable methodologies has kept these operations at a very small scale and limited the development of mariculture in Zanzibar.

One of the main challenges for the development of mariculture in Zanzibar (and Africa in general) is to avoid the mistakes that have been made in Asia and South
America (Mafwenga, 1994). In these regions pollution, uncontrolled elimination of mangrove forests and saltwater intrusion into land have ruined many nearshore ecosystems, especially mangroves (Kapetsky, 1986).

Mariculture experiments at the Institute of Marine Sciences (IMS) of the University of Dar es Salaam began in the early 1980s (Bwathondi, 1981, 1982, 1986; Bwathondi and Ngoile, 1982; Jiddawi, 1989, 1995). More recently, IMS has received increasing numbers of requests for advice on fish, shellfish and crustacean culture (Mmochi and Jiddawi, 1996). The Institute saw the need to develop human and laboratory capabilities for mariculture research and development, so that sound advice could be given to potential farmers and policy makers. Toward this end, IMS conducted a series of studies on the possible impact of mariculture on the environment, in preparation for developing pond mariculture in coastal areas of the Zanzibar Islands (Mmochi, 1995; Mmochi et al., 1996, 1997).

The project described in this paper is a result of collaboration between IMS and scientists from the National Centre for Mariculture (NCM) in Eilat, Israel, beginning in July 1995. It deals with the adaptation of NCM’s Integrated Mariculture Pond System (IMPS) concept to local conditions in Zanzibar.

The IMPS was designed to create an economically viable production system with reduced organic and inorganic output to the environment. IMPS utilises a modular flow system of ponds for production of fish, shellfish and seaweed, in which shellfish remove particulate matter from fish pond effluents, algae remove dissolved nutrients, and clean water is returned to the environment (Mozes and Saban, 1995; Shpigel et al., 1993).

The aims of this project have been to demonstrate a prototype IMPS within the environmental, socioeconomic and technological conditions that prevail in Zanzibar, and to enhance IMS’ capabilities for mariculture research and development. Of the three basic requirements for sustainable mariculture, i.e. adequate water quality, reliable supply of formulated feeds and reliable source of seed stock, the project focused on finding solutions to the first two. Fingerlings are, at this stage, collected from the wild.

SYSTEM DESIGN AND INSTALLATION

The site of the IMPS pilot project in Zanzibar is at Makoba, on the west side of Kiwani Creek (Figure 1). A set of existing salt evaporation pans spread over five to six hectares was made available to the project (Figure 2). The salt pans are owned by the local government and had not been in use for several years. Infrastructure included a water reservoir, channels to direct water to the pans, broken water gates, and earthen dykes and embankments.

The site is located in a mangrove estuary fed by two rivers, the Zingwezingwe and the Mwanakombo, which flow into the creek (Figure 3). When the site was first visited by project staff in 1996, the spring tide filled the salt pans with seawater because the gates were broken. In 1997, several gates were reconstructed (Figure 4), and water
Figure 1. Makoba Bay showing the salt pans and the rivers

Figure 2. Evaporation salt pans at Makoba
Figure 3. Mahonda-Makoba drainage basin
from the ocean now comes into the pans/ponds only through the reservoir. Water flow through the ponds is controlled by opening and closing a gate between the reservoir and the ponds.

The maximum tide range in the estuary is about 4.4 m. The river basin is also home to a rubber farm, a sugarcane plantation, several rice farms, a sugar factory and a rubber factory. The farms and factories may occasionally introduce fertilisers and toxic materials into the river (Mohammed, 1990; Mmochi and Mberek, 1998). However, a rough estimation of the river’s flow rate made on 1 August 1996 found the water flow to be 1000 to 2000 m³/h. This is about three orders of magnitude lower than the flow rate at mid-high tide (1.4 million m³/h), suggesting that contamination would be diluted to acceptable levels during high tides.

Water quality measurements revealed that during flood tide, salinity in the estuary increases to approach that of seawater. At the same time, dissolved oxygen (DO) levels increase to saturation values and nutrient concentrations decrease. The water quality values were below the maximum allowed for recreation and mariculture activities (DENR administrative order No. 34, 1990). These findings favour drawing water for the ponds from the estuary at high tide.

**Tide measurement and analysis**

A pressure gauge was installed in the vicinity of the main water gate in late 1996. One month’s records (18/9/96–16/10/96) were analysed and compared with British Admiralty Tide Tables for Zanzibar Harbour. High tides at Makoba were found to lag behind high tides at Zanzibar Harbour by about 30 to 50 minutes. The tidal amplitudes and fluctuations (at high tide) were found to be about the same. It is not possible to compare the time of low tide because the pressure gauge was situated above the low water level. Anecdotal
observation suggests that there is a delay of about two hours in the low tide at the estuary compared with Zanzibar Harbour, but this has not been confirmed. The tide and pressure gauge data are presented in Figure 5. A Tide Table datum (TTd) was marked at the Makoba site, and the tide table was then used for tidal forecasts at the site and for the design of the water supply to the project ponds.

![Graph showing tide measurements at Makoba site](image)

Figure 5. Tide measurements at Makoba site (water gate) Sep–Oct 1996, Tide Table datum

**Pond and gate design**

The main gate connects the reservoir to the tidal creek and regulates the exchange of water between the reservoir and the creek. The elevation of the floor of the main gate is 0.5m below the lowest reservoir bottom elevation (9m in topographical survey datum). The height of the main gate is designed to be at the same elevation as the main ridge. The main gate rests on a 2-m-deep box-type foundation. Side walls are built across the ridge to strengthen the walls. The flow from the creek to the main gate and on to the reservoir is provided by wing walls. These walls also help to retain the earth on both sides of the gate. Two horizontal walking platforms of thick wooden planks, one on either side of the gate provide for easy operation of the flush-boards. The amount of water allowed through the gate is controlled by flush-boards made of wooden planks, 50mm thick and 300mm wide, inserted into the groove. A mesh screen is attached to a wooden rectangle and inserted into a groove of the secondary gate connecting the reservoir and the ponds. The screen is intended to prevent the exit of the cultured fish and entry of predators into the ponds.

The size of the opening of the main gate is designed such that the water flow speed is not lower than 0.3m/s to avoid silting and not greater than 1m/s to avoid scouring. For example, if the reservoir is filled to 0.9m above its bottom and the average
time to fill it is 6.2 hours (diurnal tides), the area (A) of the sluice opening for a water speed (V) of 1m/s is about 3m², requiring a minimum opening of 1.2m with a gate height of 2.5m.

**Water supply**
The existing reservoir has a surface area of approximately 40,000m², and an average bottom elevation of 3.6m above sea level (TTd). Spring tides range from 0.25 to 0.9m above this average reservoir bottom elevation (using British Admiralty Tide Tables for 1997). The reservoir is filled at each spring tide, providing at least 10,000m³ of water. This water must last through the neap tide cycle, until high tides again exceed the reservoir bottom elevation, in about 10 days. Thus, the reservoir can provide 1000m³ of water per day at the minimum (30% of the time).

A simple dynamic model was developed to guide the operational management of the reservoir. An example of simulation of the flow and water level in the reservoir during four days surrounding a spring tide is presented in Figure 6.

**Ground water observations**
The high ground-water table at Makoba raised concerns of fresh water intrusion into the ponds after they were deepened. On 21 and 23 March 1997, ground water was sampled at Makoba to determine its depth, salinity, and changes over the tide cycle.

A 1-m-deep hole was made in the middle of the salt pan area. Salinity and water level were measured simultaneously in this hole and at the main reservoir gate. Water

![Graph](image)

Figure 6. Flow model—Tide at Makoba IMPS. Simulation of 4 days at spring tide

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level and salinity in the hole were found to be largely constant over the tidal cycle (Figure 7). The findings suggested that fresh groundwater intrusion at Makoba will not be a problem for aquaculture.

![Graph showing salinity and depth over time](image)

**Figure 7.** Water depth and salinity of the water hole and main gate 22–23 March 1997, Makoba

**Pond construction**

Six of the existing salt pans at Makoba were divided into two series of three ponds each, and dug to accommodate a water depth of 0.6–0.7m. The final size of the ponds is 20 x 13m (260m²) with an estimated volume of 170m³. Sediment in the ponds was black mud, probably containing high levels of organic matter, which originated from the mangrove swamp that existed before the salt works were built.

Each set of three ponds was arranged in a row so that water released from the tidal reservoir enters the 1st (fish) pond, pushing the water from that pond into the 2nd the (shellfish) pond and the water from the shellfish pond into the final (seaweed) pond. From the last pond, water travels to a holding basin for return to the sea when the tide is appropriate. Wooden gates with mesh windows separate the ponds from each other and prevent movement of fish between the ponds. A concrete gate with wooden doors at the exit of the seaweed pond determines the water level for the three ponds.

**Oxygen considerations and water flow regime**

The water exchange rate (ER), is determined by the water flow rate (Q) and the water volume (V) of the pond (ER=Q/V). At low ER (ER<0.5 per day) the water quality is
dominated by phytoplankton activity. At a higher ER (ER>1.5) the water quality conditions are more stable and are dominated by the fish biomass (Mozes and Argaman, 1995). Since mechanical aeration for oxygen supply was not to be used at the Makoba site, the water exchange rate was designed to maintain reasonable water quality and oxygen levels for the culture of the fish. An ER of 1 to 2 exchanges per day was assumed to allow final fish density of 1kg/m$^3$.

**Diet development and feeding experiments**

Farming of rabbitfish under semi-intensive or intensive conditions requires the use of formulated fish feeds to guarantee that the fish will receive the necessary nutrients to grow. In this project, rabbitfish (*Siganus* sp.) were to be raised for local use in Zanzibar. Therefore, the cost had to be low enough to compete with local market prices. This meant that a fish feed manufactured from locally available feed ingredients was preferred, as it was most likely to keep the cost of growing the fish at an affordable level.

In 1997, a survey and evaluation of feed ingredients available in Zanzibar to identify raw materials that could be used to formulate rabbitfish feed was conducted. Available feed ingredients were shipped to the NCM nutrition laboratory and analysed for approximate compositions. The ingredients included 8 species of legumes from genus *Leucaena* and 2 species of algae from genus *Eucheuma*. Other ingredients were anchovy, coconut cake, sardines, rice bran, broiler mash and growers mash. Ingredient prices and availability throughout the year were also considered. The results of ingredient analyses are shown in Table 1.

Based on the composition and price data for ingredients from Zanzibar, two diets were formulated using a computer least cost formulation program developed for the feed industry. The diets formulated were for a primary herbivore whose main source of dietary protein is plants. The composition of the diets are given in Table 2.

Dietary trials were conducted at the NCM, using locally available rabbitfish species (*Siganus canaliculatus* and *Siganus sutor*), which are also present in Zanzibar. The results obtained in the NCM trials were then tested on a larger scale in the ponds in Zanzibar. The feeding trials were designed to test each of the two diets at two different feeding levels: maximum consumption, and 50% of the maximum representing 1 and 2% of the fish’s body weight. Rabbitfish are grazers and spend most of their time feeding. As a result, it is important to know whether they require large volumes of feed or can thrive on smaller quantities of food of a higher total nutrient concentration.

Within 10 days of the start of the feeding trial, fish started to die in all of the fish tanks. Pathological examination indicated no obvious parasitic or bacterial infections, suggesting the possibility of a toxin in the feed. To test the feed ingredient toxin hypothesis, each of the feed ingredients was individually combined with known ingredients routinely used at NCM. These five new diets were then tested on healthy rabbitfish in the same type of feeding trials. Within 10 days of the start of this trial, the tanks fed with the legume 5 developed the same pathology as in the initial study, and fish began to die. It was then clear that the cause of the mortality was from legume 5.
Table 1. Composition of feed ingredients from Zanzibar (in percent as fed)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Moisture</th>
<th>Protein</th>
<th>Lipid</th>
<th>Ash</th>
<th>Carbohydrate</th>
<th>Energy (cal/g)</th>
<th>Phosphorous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume 1</td>
<td>11.1</td>
<td>23.32</td>
<td>4.38</td>
<td>12.27</td>
<td>11.07</td>
<td>4128</td>
<td>0.29</td>
</tr>
<tr>
<td>Legume 2</td>
<td>12.82</td>
<td>26.71</td>
<td>2.59</td>
<td>12.48</td>
<td>11.58</td>
<td>4238</td>
<td>0.36</td>
</tr>
<tr>
<td>Legume 3</td>
<td>11.17</td>
<td>24.94</td>
<td>4.42</td>
<td>9.32</td>
<td>12.23</td>
<td>4474</td>
<td>0.42</td>
</tr>
<tr>
<td>Legume 4</td>
<td>10.18</td>
<td>21.93</td>
<td>14.13</td>
<td>12.59</td>
<td>17.28</td>
<td>4458</td>
<td>0.24</td>
</tr>
<tr>
<td>Legume 5</td>
<td>11.1</td>
<td>26.23</td>
<td>6.5</td>
<td>10.12</td>
<td>24.67</td>
<td>4139</td>
<td>0.26</td>
</tr>
<tr>
<td>Legume 7</td>
<td>12.83</td>
<td>24.51</td>
<td>5.03</td>
<td>9.61</td>
<td>15.88</td>
<td>4293</td>
<td>0.17</td>
</tr>
<tr>
<td>Legume 8</td>
<td>4.41</td>
<td>33.67</td>
<td>4.84</td>
<td>13.43</td>
<td>12.31</td>
<td>4392</td>
<td>0.17</td>
</tr>
<tr>
<td>Anchovy</td>
<td>11.14</td>
<td>73.45</td>
<td>9.88</td>
<td>11.87</td>
<td>–</td>
<td>4555</td>
<td>2.55</td>
</tr>
<tr>
<td>Coconut cake</td>
<td>11.24</td>
<td>24.04</td>
<td>8.06</td>
<td>5.94</td>
<td>24.07</td>
<td>4305</td>
<td>0.84</td>
</tr>
<tr>
<td>Sardines</td>
<td>19.36</td>
<td>63.72</td>
<td>6.61</td>
<td>12.65</td>
<td>–</td>
<td>4028</td>
<td>2.04</td>
</tr>
<tr>
<td>Rice bran</td>
<td>9.37</td>
<td>5.64</td>
<td>4.56</td>
<td>18.96</td>
<td>26.85</td>
<td>3452</td>
<td>0.58</td>
</tr>
<tr>
<td>Maize bran</td>
<td>11.26</td>
<td>10.35</td>
<td>8.84</td>
<td>2.07</td>
<td>55.51</td>
<td>4424</td>
<td>0.35</td>
</tr>
<tr>
<td>Broiler mash</td>
<td>11.19</td>
<td>16.92</td>
<td>6.93</td>
<td>7.37</td>
<td>47.23</td>
<td>4027</td>
<td>0.59</td>
</tr>
<tr>
<td>Growers mash</td>
<td>11.25</td>
<td>13.62</td>
<td>6.83</td>
<td>6.48</td>
<td>50.74</td>
<td>3899</td>
<td>0.51</td>
</tr>
<tr>
<td>Eucheuma cottonii</td>
<td>14.23</td>
<td>0</td>
<td>0.87</td>
<td>42.54</td>
<td>25.36</td>
<td>1847</td>
<td>0.09</td>
</tr>
<tr>
<td>E. spinosum</td>
<td>16.33</td>
<td>0</td>
<td>0.84</td>
<td>52.42</td>
<td>21.28</td>
<td>1687</td>
<td>0.04</td>
</tr>
<tr>
<td>E. cottonii washed</td>
<td>16</td>
<td>–</td>
<td>–</td>
<td>24.18</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>E. spinosum washed</td>
<td>8.4</td>
<td>–</td>
<td>–</td>
<td>18.43</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: Analyses were carried out at National Centre for Mariculture, Israel. – not analysed.

Table 2. Percent composition of formulated diets for rabbitfish

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>25% protein diet</th>
<th>32% protein diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume 5</td>
<td>19.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Coconut cake</td>
<td>21.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Maize ban</td>
<td>21.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Broiler mash</td>
<td>21.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Sardines</td>
<td>18.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Total feed</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Estimated cost (TSh.)</td>
<td>35</td>
<td>42</td>
</tr>
</tbody>
</table>

(Leucaena). A meal made from the leaf of this plant contains an antinutrient called mimosine that is known to retard growth in fish and can be removed through pretreatment of the plant before use in feeds (Coche and Edwards, 1989). The feed was remade using presoaked Leucaena and used successfully. However, Leucaena was later replaced with Ulva reticulata, which has the same protein: carbohydrate composition.

In June 1998, a trial production of fish feed was undertaken in Zanzibar. As a replacement for legume 5, fresh seaweed from the local beaches was obtained. The seaweed (Ulva reticulata) was rinsed with fresh water, sun dried, milled and mixed with the other ingredients. Initially, pellets were made using a kitchen meat mincer (commercial meat mincers or industrial pelleting machines might be used in future).
Later, an experiment was done with the feed in the form of balls. The balls (approximately 70g each) were made from the mixed ingredients using 5% cassava as a binder, and dried in the sun to harden. Initial feeding trials with the balls indicated the fish ate them enthusiastically. Since this is also a cheaper option for the fish farmers, the making of the balls was continued. Table 3 provides data on the feed’s composition and cost in Zanzibar.

<table>
<thead>
<tr>
<th>Component</th>
<th>Price (TSh./kg)</th>
<th>Fraction (%)</th>
<th>Cost (TSh./kg food)</th>
<th>Percentage of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copra cake</td>
<td>30</td>
<td>17.4</td>
<td>5.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Fish meal</td>
<td>450</td>
<td>28.6</td>
<td>128.7</td>
<td>48.9</td>
</tr>
<tr>
<td>Broiler mash</td>
<td>156</td>
<td>17.14</td>
<td>26.7</td>
<td>10.1</td>
</tr>
<tr>
<td>Ulva</td>
<td>500</td>
<td>15.2</td>
<td>76.0</td>
<td>28.9</td>
</tr>
<tr>
<td>Maize bran</td>
<td>100</td>
<td>17.14</td>
<td>17.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Cassava</td>
<td>200</td>
<td>4.8</td>
<td>9.6</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>263.2</strong></td>
<td><strong>100.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Stocking of ponds**
Approximately 4000 rabbitfish (a mixture of *S. canaliculatus* and *S. sutor*) fingerlings were collected and transferred to the project’s pond during June and July 1998. The fingerlings were collected with the aid of a 25m beach-seine net at high tide on the beach next to the Institute of Marine Science in Stone Town, Zanzibar. Transportation of the fish to Makoba was carried out using a compressed air supply from scuba tanks and an air diffusing system. All fish were successfully transported and stocked in the two fishponds with no mortality (about 2000 fish in each pond). Samples of about 50 fish each were weighed individually before the two separate transports, yielding average fish weights of 5.7 and 7.1g.

Two species of locally occurring shellfish—*Anadara* sp. and *Cardium* sp.—were collected from the inter-tidal zone south of Stone Town. They were kept alive in the IMS aquarium tanks for a few days before weighing, sorting and stocking during June 1998 at Makoba. During their stay at IMS, a power failure occurred one night, and oxygen levels in their holding tanks dropped significantly. It is not known whether the mortality observed at a later date was related in part to this oxygen depletion.

Measurement of the shellfish indicated a weight range of 10 to 45g and length range between 20 and 50mm. Both species were of similar average weight and their length/weight relationship was calculated as:

\[ W = 0.0025 \times L^{0.248} \quad (R^2 = 0.84) \text{ for } Anadara \text{ sp. (n=346)} \]

\[ W = 0.0024 \times L^{0.251} \quad (R^2 = 0.93) \text{ for } Cardium \text{ sp. (n=182)} \]

The shellfish were stocked using three different methods:
(1) Suspended above the pond bottom on plastic trays, which were supported by wooden stacks embedded in the pond mud (400 individuals of Anadara sp. and 100 of Cardium sp.).

(2) Placed directly on the pond bottom at a density of 400 ind./m² (200 ind. of Anadara sp. and 200 of Cardium sp.).

(3) Put on nylon fishing net on the bottom of the pond (200 ind. of Anadara sp. and 200 of Cardium sp.). Total stocking in the pond was 800 ind. of Anadara sp. and 600 ind. of Cardium sp.).

Two species of seaweed, Eucheuma spinosum (E. denticulatum) and Euchema cottonii (Kappaphycus alvarezii) were collected from the inter-tidal zone on the east coast of Zanzibar in the area of Matemwe and stocked in Makoba the same day. Approximately 20kg of each species were stocked using the local method of tying branches of seaweed along a string at a depth of 20cm above the bottom. The estimated stocking density was 1kg/m. Ulva fasciata, U. reticulata and Gracilaria crassa were also stocked. Ulva and Gracilaria were cultured in small chambers made of netting material of 1 inch mesh size.

Data collection and daily operation
During each spring tide, the reservoir was filled with seawater from the estuary. Water was supplied from the reservoir to the fish ponds every day in the afternoon, when oxygen levels were high due to photosynthesis in the reservoir. The planned water flow to each pond was 200m³/day, and was accomplished by flushing water until the reservoir water level (RWL) dropped 0.5cm. Fish were fed three times a day by hand, at about 1% of body weight per day. Seaweeds were weighed once a week using a commercial weighing balance. Temperature and dissolved oxygen were measured three times a day in all ponds and the reservoir using an Oxyguard DO meter, calibrated for seawater salinity. Salinity was also measured thrice a day, using a hand-held refractometer.

PRELIMINARY RESULTS AND DISCUSSION

Water supply and salinity
The tidal flow supply model was useful as a design tool for the operation of the reservoir. In practice, however, several limitations became apparent. The reservoir bottom was not even, and only part of the water volume could be utilised for supplying the ponds. As a result, the water supply to the ponds was limited and most of the time the supply was about half of what was planned (0.25cm drop in the RWL to each fish pond, instead of 0.5cm, meaning about 100m³/day instead of 200m³/day). In addition, leaks in the reservoir walls and gates were estimated to cause a loss of 100–130m³/h. On one occasion (17–21 August 1998) the wall of the reservoir broke at one point and no sea water was supplied to the fish ponds for two weeks. The loss of water led to very low oxygen saturation (less than 50%), which is thought to have led to fish mortalities.
Salinity of the water in the ponds ranged from 36 to 40ppt, indicating that the water was coming from the marine tidal flow and not from a fresh water source such as the river or ground water. In general, the daily water exchange prevented any significant drop in salinity due to rain, except on one occasion (20–26 October 1998) when unusually heavy rains coincided with low water level in the reservoir. The salinity dropped to 22 – 20ppt in the ponds and to about 10ppt at the surface of the reservoir. This salinity drop was probably the cause of mortality of about 700 fish in both ponds.

**Water quality**

Water quality measurements in the fishponds and the reservoir showed daily fluctuations in dissolved oxygen (DO) and water temperature, with greater fluctuation in the reservoir.

Preliminary results indicate that long residence time and shallow water depth effects occur in the reservoir. The long residence time and greater clarity of water in the reservoir probably results in greater photosynthesis, and hence in larger DO fluctuations. The smaller water depth contributes to high temperature variations.

**Dissolved oxygen**

Dissolved oxygen (DO) showed rather low levels in the morning and high levels in the afternoon and evening (Figure 8). DO levels in the fishponds generally ranged from about 2.5mg/l at 0600 to about 12mg/l at 1800hrs. Average values of DO for all ponds (Table 4) show a range of about 80% of saturation in the morning to about 125% in the evening, with minimum and maximum values of 40 and 196%, respectively.

![Graph showing DO levels](image_url)

*Figure 8. Dissolved oxygen (DO) (mg/l) levels in fish pond 1 at the Makoba IMPS, Jun 1998–Dec 1998*
Table 4. Dissolved oxygen concentration, in percentage of saturation, mean values for June–December 1998 in the two rows of ponds (IMPS 1 and 2). SD values are in parentheses

<table>
<thead>
<tr>
<th></th>
<th>0600 hrs</th>
<th>1400 hrs</th>
<th>1800 hrs</th>
<th>Average</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPS 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>76 (16)</td>
<td>109 (21)</td>
<td>126 (25)</td>
<td>104 (29)</td>
<td>40</td>
<td>196</td>
</tr>
<tr>
<td>Shellfish</td>
<td>84 (12)</td>
<td>114 (15)</td>
<td>125 (17)</td>
<td>107 (22)</td>
<td>62</td>
<td>180</td>
</tr>
<tr>
<td>Seaweed</td>
<td>85 (8)</td>
<td>108 (12)</td>
<td>116 (12)</td>
<td>103 (17)</td>
<td>62</td>
<td>154</td>
</tr>
<tr>
<td>IMPS 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>79 (14)</td>
<td>105 (17)</td>
<td>120 (21)</td>
<td>101 (24)</td>
<td>46</td>
<td>176</td>
</tr>
<tr>
<td>Shellfish</td>
<td>94 (10)</td>
<td>112 (13)</td>
<td>125 (17)</td>
<td>110 (19)</td>
<td>68</td>
<td>181</td>
</tr>
<tr>
<td>Seaweed</td>
<td>90 (8)</td>
<td>112 (12)</td>
<td>121 (14)</td>
<td>108 (18)</td>
<td>73</td>
<td>165</td>
</tr>
</tbody>
</table>

In both sets of ponds, the fluctuations in DO indicated by the SD values in Table 4 and respiration rates (Figure 9) are more pronounced in the fish ponds and slightly less so in the shellfish and seaweed ponds.

**Temperature**

Temperatures also fluctuated during the day (Figure 10), with an average increase of about 2 to 4°C from morning to afternoon and an average drop of 0.5 to 1°C in the

![Graph of respiration rates in IMPS 1 and 2 ponds](graph.png)

**Figure 9. Average night respiration rate at Makoba IMPS 1&2**
Figure 10. Temperature at Makoba IMPS fish pond 1, Jun 1998–Dec 1998
evening. The average temperature increased during the year from 26.6°C in June to
31.5°C in December (Figures 11a, 11b).

CULTURE RESULTS

Fish culture

The fish in both ponds (*Siganus* sp.) showed reasonable growth during five months of
culture. In the first fish pond, fish grew from 5.7g to 34.4g (Jun to Nov 1998) and in the
second pond from 7.1g to 66g (Jul to Dec 1998). The difference in growth is attributed
to the difference in stocking size and to the higher water temperature during the later
months of the year.

Comparison of the results of the fish growth data to a growth rate model (Figures
12a, 12b) shows that the results are slightly lower (by 7 and 16% for IMPS1 and 2,
respectively) than the model prediction.

The model equation is based on the feeding experiments done at NCM, Eilat with
*Siganus argenteus* using the same feeding diet (NCM Nutrition Dep. internal report,
1998):

\[ \text{WG} = 0.0098 \times W^{0.605} \times e^{(0.055xT)} \]

where WG is the daily weight gain of one fish (g/day), W is the fish weight (g), T is
temperature (°C) and the coefficients are empirical. It appears that this equation can
be used for growth prediction until there is sufficient data to formulate the growth rate
equation for the local conditions.
Figure 11. Temperature changes in (a) the water column and (b) pond 2 at Makoba IMPS

Two mass mortalities occurred on 17–21 August 1998 and 20–26 October 1998. The first event occurred when the wall of the reservoir broke and no seawater was supplied to the fishpond for several days. The second mass mortality occurred during a few days of
heavy rains, leading to low salinity in the reservoir and the fishponds. In total, these events resulted in a loss of about 500 fish in pond 1 (25% mortality) and 830 fish in pond 2 (41% mortality). Re-suspension of the bottom sediments during fish sampling also seemed to cause mortality of fish.

All the fish that died were of the species Siganus canaliculatus (except for one specimen of S. sutor). Apparently, S. canaliculatus is more sensitive to extreme conditions and therefore may be less suitable for culture than S. sutor. In addition to the Siganus, a few specimens of milkfish and Tilapia were present; these were also in good condition.

Shellfish culture

Shellfish culture was attempted using several species: Anadara sp., Cardium sp. and oysters. The two species stocked initially (Anadara sp., Cardium sp.) did not survive the pond conditions under any of the culture techniques that were tested. Subsequently, a group of oysters (Pinctada sp.) were placed in the ponds, both inside trays and in
between trays. The oysters inside the trays showed limited growth (perhaps due to blockage of water circulation through the trays), while oysters outside the trays survived and grew.

Seaweed culture
All the seaweeds suffered from dramatic siltation from sediments and organic loads suspended in the pond. Growth rates decreased with time. Only the Gracilaria sp. showed some limited growth and resistance to siltation. Eucheuma was the most severely affected followed by Ulva and lastly Gracilaria. The first sign of stress in Eucheuma was the hardening of the fronds, followed by lightening of the colour and thinning of the seaweed fronds. One variety of E. spinosum, which was recently introduced in Zanzibar from the Philippines, and E. cottonii could not survive after two weeks of culturing, whereas the 'old variety' of E. spinosum survived for more than a month.

CONCLUSIONS
The idea of environmental friendly mariculture using the IMPS concept seems to be promising for marine aquaculture development in Zanzibar. It has been demonstrated the Makoba site, which has some unique characteristics that differ from other potential sites, creates special conditions that influence the system design and performance.

Existing infrastructure at Makoba, such as the reservoir, is not found anywhere else in Zanzibar or Pemba. The reservoir provides a daily supply of water to the ponds without any motorised pumping. On the other hand, the water that reaches the ponds is not fresh seawater, and changes in dissolved oxygen and salinity within the reservoir affect the ponds. In addition, the heavy and muddy bottom soil of the ponds, which probably contains high levels of organic matter, affects water quality and siltation in the ponds. Nonetheless, the methodology and information that have been gained from the Makoba experimental site can contribute to the development of mariculture in the region.

The tidal water supply method used at Makoba provided water quality conditions that fluctuated within the generally acceptable range of dissolved oxygen, temperature and salinity. Although the daily water flow rates were lower than planned, dissolved oxygen did not drop to levels that would cause fish mortality. Morning oxygen levels and night respiration rates were near typical levels for earthen ponds enriched with organic matter (Boyd, 1979). The results suggest that the main process governing the oxygen regime is photosynthesis, with a significant contribution to total pond oxygen demand coming from the muddy bottom. It is likely that an increase in water flow and a lower organic load from the bottom sediments would make the oxygen regime more favourable to fish culture.

The fish growth rate was relatively close to the model growth rate achieved in experimental tanks that had excellent water quality. Although massive fish mortality occurred during the operation, the fish culture results are encouraging. The reasons for the mortality are thought to be related to technical problems in the reservoir operation,
which can be corrected by deepening the reservoir and securing its walls.

The system at Makoba has not yet demonstrated the integration of shellfish and seaweed as part of the environmental approach since the culture of these two species is still not successful. The species and culture techniques that were tested for shellfish and seaweed did not offer an adequate solution. However, the nutrient levels in the ponds were still three orders of magnitude below the maximum levels allowed for recreational and mariculture activities (DENR administrative order no. 34, 1990), implying the experiment can go on while suitable species of shellfish and seaweed are identified. Additional experimental work is presently underway at Makoba to solve the difficulties identified in this study.

REFERENCES


DENR administrative order No. 34 1990. Revised water usage and classification/water quality criteria amending section Nos 68 and 69 chapter 3 of the 1978 NPCC rules and regulations, Manila, Philippines. 9 pp.


Department of Environment, Zanzibar. 54pp.
Establishing the status of the environment and environmental changes in Tanzania coastal waters

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²Coastal Resource Center, University of Rhode Island, USA

ABSTRACT

To develop integrated coastal management (ICM) it is necessary to have baseline information on the state of the environment. Furthermore, as the developments are going on, monitoring is necessary to identify changes in the environment and mitigate pollution. It is also necessary to link scientists and managers to facilitate use of the collected data in decision making.

The Tanzania Coastal Management Partnership (TCMP) organised a Marine Environment Assessment and Monitoring Coordination Team (MEAMCOT) to assess, review and collect baseline information on marine research in Tanzania. This paper discusses activities of MEAMCOT from January to May 1999 that involved developing a bibliography and annotated bibliography of studies in marine sciences in Tanzania. The literature obtained has been synthesised to expose gaps in data and information. The synthesis is summarised in a map that shows the areas where actual field data have been collected. Furthermore, human and laboratory capacities in different organisations are discussed, and relevant sources of information that may be useful to marine sciences (e.g. from ports, hospitals, hydroelectric power stations, etc.) are explored. A rudimentary plan for long-term monitoring of the Tanzania coastline is discussed, including the role of scientists, communities and managers. The plan includes primary data collection through direct monitoring, obtaining and analysing seldom published data that is regularly collected in related government institutions, NGOs and research stations, and the use of questionnaires to obtain information from communities in the study areas.

INTRODUCTION

A workshop on ‘Marine and Coastal Risk Assessment: An Approach for Linking Science and Integrated Coastal Management Programme’ was held at the Institute for Marine Sciences in July 1998 (Ngoile et al., 1998). The workshop identified three key elements of a national coastal resource baseline:
1. Pressures — increase in number and diversity of human activities on the coastal ecosystems
2. State — status of coastal resources and ecosystems
3. Response — governance response to coastal issues

Across the three elements, a common weak area was found to be the level of information available on various subjects including coastal and marine resources, marine pollution and degradation of the coastal environment (Stolla et al., 1998). The weaknesses in information availability and exchange are also mentioned by Garber (1998). It was noted that marine research institutions in Tanzania are not adequately mobilised or coordinated to address the critical areas and issues (Tanzania Coastal Management Partnership (TCMP) Support Unit, 1998). Furthermore, there is need of a forum for scientists and managers to exchange information and establish priorities on the important management questions facing the nation. It is on this basis that the Marine Environment Assessment and Monitoring Coordination Team (MEAMCOT) was formed. MEAMCOT collected, analysed and synthesised available information on various topics in marine sciences and in the process identified gaps of information in five subject areas of concern.

The issue of information availability and its use in decision making has been discussed at various fora (e.g. UNEP/ Institute of Marine Sciences (University of Dar es Salaam)/FAO, (1997)). On 12 May, 1999 a meeting of directors of the institutions related to environment issues in Tanzania adopted information availability as one of seven critical national coastal management issues facing Tanzania. The lack of data on coastal and marine resource status, trends and use inhibits good planning and proper management. Accordingly, the TCMP approved the following goal (TCMP Support Unit, 1999):

"Improve the ability of science to inform decision-makers as they make resource use and allocation decisions by supporting a national coastal ecosystem applied research, monitoring and assessment program that provides useful information to decision-makers."

TCMP developed five broad strategies to address this issue. The strategies were developed as a result of a comprehensive process of meetings and consultations with stakeholders at the national and local levels led by the TCMP. The strategies were presented to directors of institutions dealing with marine sciences in Tanzania and adopted in the order of priority listed below:

1. Provide researchers and research organisations priority coastal management issues for management-related research and ongoing monitoring of the health of the coastal ecosystem. Ensure that this information is used to drive data acquisition.
2. Develop and operate a simple but effective coastal ecosystem research monitoring and assessment system that will allow already available—as well as new—scientific
and technical information to influence coastal management decisions. This should be accomplished using existing research and monitoring institutions.

3. Foster long-term working relationships and create administrative structures that facilitate scientific input into management at the national and local level.

4. Make information about coastal management and ongoing monitoring (biological and socioeconomic) available to resource managers and the public.

5. Provide financial resources and other support to the existing data collection and delivery centres.

To address the issue of information availability for decision making, and as a follow up to the July 1998 Workshop, an interim MEAMCOT was formed. MEAMCOT’s goal is to use existing human capacity (scientific, managerial and community) to stimulate, gather and deliver useful information on the conditions and pressures on the coastal and marine environment for management and public awareness purposes. The terms of reference of MEAMCOT are to:

- Stimulate scientific monitoring and analysis of information on the conditions and pressures on marine ecosystems
- Design and test monitoring approaches that respond to integrated coastal management questions
- Organise multidisciplinary teams for the synthesis and translation of scientific information for management purposes and public awareness.

The interim group held three meetings (in January, March and May, 1999) and supervised work activities that resulted in draft reports on information availability and gaps, coastal ecosystem monitoring, and a directory of marine scientists working in Tanzania. The core interim team was comprised of eight members:

Chair: Mr. A. Mmochi, Institute of Marine Sciences, Zanzibar
Advisor: Dr. J. Tobey, The Coastal Resources Center, University of Rhode Island
Ms N. Jiddawi, Institute of Marine Sciences, Zanzibar
Dr D. Masalu, Institute of Marine Sciences, Zanzibar
Mr A. Kamukuru, Kunduchi Fisheries Institute, Dar es Salaam
Mr S. Mahongo, Tanzania Fisheries Research Institute, Dar es Salaam
Dr Y. Mgaya, Zoology and Marine Biology Department, University of Dar es Salaam
Dr D. Mashauri, Civil Engineering Department, University of Dar es Salaam.

The activities of MEAMCOT are described in the sections that follow.

**A: REVIEW AND SYNTHESIS OF EXISTING KNOWLEDGE**

A major element of the initial work of MEAMCOT was directed at surveying existing information and assessing its relevance and quality. The goal of this work is to help identify the important gaps and deficiencies in existing scientific knowledge and to determine the extent to which critical environmental and resource issues are covered
by topic and geographic area. The work also evaluates the importance of the available information on coastal management decision making and identifies data, information, and research needed to reduce uncertainties and possibilities of filling gaps and deficiencies within a realistic time frame.

A bibliography and annotated bibliography are being prepared on the following topics:
1. Water quality and coastal pollution
2. Coral reefs and fisheries
3. Mangroves
4. Coastal erosion
5. Other living marine resources.

To date, some 627 references have been noted in the bibliography of which 205 references of studies that involved direct field data (as opposed to surveys and reviews) were used to make an annotated bibliography (Table 1). Experts in the respective fields of studies wrote four syntheses reports from the annotated bibliography.

Table 1. No. of references used in the bibliography and annotated bibliography

<table>
<thead>
<tr>
<th>Topics</th>
<th>Number of references in bibliography</th>
<th>Number of references in annotated bibliography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water quality and coastal pollution</td>
<td>75</td>
<td>13</td>
</tr>
<tr>
<td>Coral reefs and fisheries</td>
<td>182</td>
<td>129</td>
</tr>
<tr>
<td>Mangroves</td>
<td>83</td>
<td>40</td>
</tr>
<tr>
<td>Coastal erosion</td>
<td>109</td>
<td>23</td>
</tr>
<tr>
<td>Other living resources</td>
<td>178</td>
<td>Not complete</td>
</tr>
</tbody>
</table>

The synthesis reports addressed seven points:
1. Whether pertinent data/information exists, when and where it was collected, and how reliable it is.
2. Explanations on methodologies used and whether the results of separate studies are comparable.
3. The main results.
4. Whether information from specific studies on extent and conditions of the environment can be extrapolated to unstudied areas.
5. Whether the results can be used in management decisions.
6. Identification of the main gaps of information.
7. Recommendations for the future.

A summary of the synthesis reports and comments made during their presentations are as follows:
1. Water quality and coastal pollution (A. J. Mmochi, IMS)

Very little field data are available and most of the available information is qualitative. Most of the quantitative studies were conducted in Dar es Salaam and Zanzibar. In Dar es Salaam, most studies have been done on the Msimbazi Creek, the port area and the coastal waters. In Zanzibar, Chwaka Bay is the most studied area. The issue of pollution is thought to be localised near townships, although there are not adequate field data to prove this. Water quality studies are not a priority in the National Environment Management Council (NEMC).

- Poor coverage of studies especially where actual field data are concerned. Only thirteen studies with field data are reported and were mostly done in Dar es Salaam and Zanzibar.
- No studies were conducted at the main river mouths, which may carry agricultural chemicals and sediments into the coastal waters.
- There are few studies on heavy metals and pesticide pollution in the waters of coastal towns and estuarine areas.

Comments
- There is a need to introduce appropriate technologies to monitor water quality.
- Water quality needs to be studied/monitored at river mouths and estuaries.
- Water quality studies need to be conducted in Tanga, Mtwara, Lindi and other townships hitherto unstudied.

2. Coral reefs and fisheries (N. Jiddawi, IMS and H. Machano, Department of Environment, Zanzibar)

(a) Coral reefs

Most research work on coral reefs has been conducted around Mafia, Dar es Salaam, Tanga and Zanzibar coastlines.

The following gaps were identified:
- Study distribution was poor and performed mostly near institutions dealing with marine sciences or ongoing projects.
- There was little work done in Pemba, Mtwara and Lindi.
- Methodologies differed and the information obtained in different areas is often not comparable.
- Taxonomic information, which is basic in biological studies, is lacking in most of the literature. Sometimes only common names are used.

Efforts are now being made to establish standard methods for coral monitoring through a national monitoring plan. The standard methods for coral reef monitoring is currently used in Zanzibar coral studies by the Institute of Marine Sciences.
Comments
- To facilitate comparison between studies the methods need to be standardised.
- Coral reef research should be oriented to management needs.
- The issue of coral bleaching needs to be studied in more detail.
- Studies on restoration of coral need to be enhanced.

(b) Fisheries
Most studies have been conducted only in areas where there were marine sciences institutions or on-going projects.
- Most studies were short-term.
- Methodologies were not consistent.
- Quantitative studies of offshore fisheries were not available.
- The effect of the 'Uzio' fishing method is not known (fish catch by this method has not been monitored).

Comments
- Fishery biology studies focused on a few species.
- More studies are required.

3. Mangroves (S. Khiai, Department of Environment, Zanzibar)
Most studies in Tanzania were conducted in the Rufiji River Delta. There are only a few studies in the other mangrove areas, notably Mtwarra and Tanga. Many gaps of information were identified.
- The last survey (Semesi, 1991) assessing the status of mangrove ecosystems is over 10 years old and it is thought necessary that another study be carried out for comparison purposes.
- The mangrove area cover from different researchers differed without explanation of the difference, which may be due to differences in calculation methodologies and the time of the sampling.

Comments
- There is a need to revisit Semesi (1991) baseline information and check whether any changes have occurred so far.
- It is necessary to check whether the NORAD management plans (Semesi, 1991) are still valid.

4. Coastal erosion (D. Masalu, IMS)
Although many factors have been cited as causes of coastal erosion, it is difficult to determine the main cause and hence to suggest mitigation measures. As a result mitigation is addressing the various issues on a case-by-case basis. The setback line, for example, has been changed from 200m through 100m to the present 60m from the highest water mark.
Geographical coverage is poor, with the most studied area being Dar es Salaam.
- There is an imbalance of available data, e.g. no wave or current data for Tanga.

Comments:
- The main causes of coastal erosion are still not known (sand extraction, reef blasting, etc.) and more research is needed in this area.
- There is a bigger vision of protection (personal property protection), that does not follow official scientific and management policies. Appropriate ways of dealing with this need to be identified.

5. Other living resources (N. Jiddawi, IMS)
Methodologies varied depending on the resources. There were also methodological differences even among studies of the same resources, especially those investigating seaweeds.
- The following gaps were identified:
  - There were few studies on marine mammals.
  - Most studies were short-term.

Comments:
- Studies on sea birds and seagrasses are missing.

B: DIRECTORY OF MARINE SCIENTISTS
As part of a long-term strategy to strengthen the national network of scientists and their institutions, the group circulated, through the institutions dealing with marine sciences, a questionnaire with the objective of establishing a Directory of Coastal and Marine Scientists working in Tanzania. In the first round of responses, about 50 responses were received. The initial results are summarised in Table 2. The Directory complements other lists such as those of the IOC (http://ioc.unesco.org/ioc/web, 1999) and Western Indian Ocean Marine Scientists Association (WIOMSA). It was noted that the IOC directory consisted of marine and freshwater scientists in Tanzania. However, its list is

<table>
<thead>
<tr>
<th>Directory</th>
<th>...Tanzania</th>
<th>...WIOMSA</th>
<th>...IOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanzania and...</td>
<td>63</td>
<td>120</td>
<td>54</td>
</tr>
<tr>
<td>WIOMSA and...</td>
<td>59</td>
<td>120</td>
<td>33</td>
</tr>
<tr>
<td>IOC and...</td>
<td>40</td>
<td>33</td>
<td>54</td>
</tr>
<tr>
<td>Tanzania but not...</td>
<td>–</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>WIOMSA but not...</td>
<td>61</td>
<td>–</td>
<td>109</td>
</tr>
<tr>
<td>IOC but not...</td>
<td>24</td>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td>In all directories</td>
<td>21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
not extensive. All the scientists in the directory are from University of Dar es Salaam and Tanzania Fisheries Research Institute. In the University, the list is drawing mostly from Institute of Marine Sciences and Zoology and Marine Biology Department. On the other hand the WIOMSA directory is restricted to members of WIOMSA. The intended directory is directed to all individuals working part-time or full-time in the marine environment even when their institutional affiliations are not specifically oriented towards marine research. In this context, efforts were made to reach diverse groups such as coastal regions and district employees, water department, ports, forestry, etc., who are often not included in other directories. Before the final document is completed the secretariat will mail to all members of WIOMSA and IOC directories requesting permission to include them in the list. The secretariat intends to request the members who do not want to be included to respond within a given period of time. This will allow the Directory to have all the members of WIOMSA and IOC as well as the new ones. It is intended that the list would be regularly updated, expanded, and made available electronically and by mail.

C: ON-GOING MONITORING PROGRAMMES

In order to choose proper methodologies for the long-term plan, the group conducted a preliminary assessment of on-going monitoring efforts. In the first meeting of MEAMCOT, guidelines for the preparation of reports on the status of on-going coastal and marine ecosystem monitoring were developed. Six reports of on-going monitoring efforts were prepared using the following guidelines:
- Describe how and why the monitoring programme was initiated.
- Explain why the particular area or ecosystem was chosen.
- What aspects are monitored? What parameters are collected?
- Where are the sampling stations? How were they chosen?
- When was it started? When is it anticipated to end?
- What is the frequency of data collection (time/tide level/seasons)?
- Who collects samples/data?
- What are the main data/sample collection methods and instruments used?
- How are samples/data analysed? By whom?
- What laboratory is used?
- How many staff operate the laboratory? What are their qualifications?
- What other types of analyses is the laboratory capable of doing?
- How are data stored (electronic or hard copy)?
- Are data accessible? How (electronic or hard copy)? By whom?
- Are the data sold or given free of charge? If sold what is the price per unit?
- How are monitoring data used (research reports, information to government, etc)?
- Are the data used for modelling?
- What decisions on resource use and quality does it intend to inform?
- Have the data been used to influence management decisions?
If finances were available would you like to extend your study to other geographic areas or start new topics? Explain briefly.

Kindly provide a bibliography of all papers, reports etc. written for your programme.

Six reports were written on different subjects. The contents of the reports and the general evaluation of the team are summarised in Table 3. The actual areas where field studies were carried out and the subjects covered are shown in Figure 1.

Each of the monitoring programmes had some elements that could be used to build up a long-term plan. Many aspects and methodologies of the coral reef and fisheries monitoring programmes can be modified to fit into citizen monitoring. The tide, bathymetric and meteorological data can also be made available to scientists for analysis. Some permanent benchmarks and tidal staffs can be used to assess beach profiles, coastal erosion and tides. In water quality some easy-to-read gadgets can be used for analysis of dissolved oxygen, pH, salinity, temperature etc.

Table 3. Monitoring report contents and evaluation regarding applicability in a citizen based monitoring programme

<table>
<thead>
<tr>
<th>Institution and authors</th>
<th>Location</th>
<th>Subject</th>
<th>Methodology</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontier-Tanzania (J. L. Solandt)</td>
<td>Mnazi Bay</td>
<td>Coral reefs (general)</td>
<td>Diving, marking and recording</td>
<td>Applicable</td>
</tr>
<tr>
<td>Institute of Marine Sciences (C. Muhando)</td>
<td>Zanzibar</td>
<td>Coral reef cover and population dynamics</td>
<td>Diving and collecting samples for laboratory analysis</td>
<td>Not easily applicable</td>
</tr>
<tr>
<td>Tanzania Fisheries Research Institute (S. Mahongo)</td>
<td>Dar es Salaam and Zanzibar</td>
<td>Tides</td>
<td>Tide gauge</td>
<td>Technical but applicable</td>
</tr>
<tr>
<td>Institute of Marine Sciences (N. Nyandwi and A. Dubi)</td>
<td>Dar es Salaam</td>
<td>Hydrography, erosion rates, bathymetry and meteorology</td>
<td>Beach grain size and profile changes; water current velocity, salinity, direction, turbidity, and temperature</td>
<td>Highly technical and hence not applicable</td>
</tr>
<tr>
<td>Institute of Marine Sciences (A. J. Mmochi)</td>
<td>Zanzibar Town coastal waters</td>
<td>Water quality</td>
<td>Dissolved inorganic nutrients, coliform, pH, dissolved oxygen and BOD</td>
<td>Highly technical in some aspects</td>
</tr>
<tr>
<td>Institute of Marine Sciences (N. Jiddawi)</td>
<td>Matemwe and Mkokotoni, Zanzibar</td>
<td>Fisheries</td>
<td>Catch statistics by species and prices</td>
<td>Applicable</td>
</tr>
</tbody>
</table>
Figure 1. Areas in Tanzania coastline where specified field data have been collected, analysed and published.
D: A PLAN FOR MONITORING COASTAL AND MARINE RESOURCES

The July 1998 meeting identified issues of concern on the Tanzania coastal and marine environment (Ngoile et al., 1998). The meeting brainstormed on availability of data, information, manpower, and gaps therein. Following the meeting an ambitious plan was made, requiring a lot of skilled manpower, equipped laboratories and financial resources (Garber and Ngoile, 1998). MEAMCOT saw this as realistic in the long-term goal with little that can be done in the near future. In the three consecutive meetings the draft has been reviewed twice to scale down the requirements in terms of laboratories, scientific manpower and financial resources.

The group prepared a draft framework-monitoring plan that relies upon three approaches. They are designed to be implemented in parallel. The approaches were chosen in order to:

1. Involve citizens and community leaders as vested members in the effort, and consequently raise environmental awareness within the community.
2. Use available manpower and institutions to reduce costs as well as increase cooperation among and between institutions, managers and stakeholders.
3. Use existing data (e.g. from hospitals, courts of law, and other district offices) and synthesise them to detect changes in the environment.

Primary data collection (field sampling of environmental parameters)

The data collection method includes scientific data sampling by both scientists in the field and citizen monitoring. Citizens would be trained to collect site-specific scientific data under the supervision of partner scientists from nearby institutions. The indicators for citizen monitoring would need to be selected based on simplicity, cost effectiveness, and effectiveness of the parameters to indicate change. It is anticipated that citizen monitoring will provide a rapid assessment means for determining critical environmental changes and targeting more in-depth studies that could be conducted by scientists as verification and assessment of the change. The results of citizen monitoring would also help determine the specific parameters that would be measured with in-depth studies.

Secondary data collection

Existing data would be collected from specific locations and partners (e.g. reports from District offices, NGOs, government agencies, etc.). Below are listed the suggested secondary data to be collected and the sources of information.

Pollution

Collect coastal hospital reports on:
- Epidemics.
- Incidences of shellfish poisoning.
- Fish poisoning.
Collect reports from agricultural officers on:
- Types of agrochemicals used in the region/district.
- Amounts of agrochemicals applied.

Mangrove ecosystems
Collect data from Regional/District forestry officers and communities on:
- Number of mangrove poles cut.
- Prices of the poles.
- Average width of the poles.
- Average length of the poles.
- Markets for the poles.
- Other commercial uses of mangroves.
- Maps, satellite imagery and aerial photographs of mangrove areas.
- Restoration projects (e.g. Fumba in Zanzibar, Mtwara etc.) and recovery in previously impacted areas.

Fisheries
Collect reports from police and courts on:
- The number of cases of dynamite fishing.
- The number of cases where poisons were used to catch fish.
Collect reports from Regional and District land officers on:
- The areas allocated for sand mining.
- The areas that are actually mined.
- The amounts of sand extracted.
- The areas allocated for coral mining.
- The areas that are actually used for coral mining.
- The amount of coral mined.
Collect reports from fisheries officers on:
- The nesting areas for turtles.
- The types of turtles caught during fishing.
- The number of eggs harvested.
- The main types of fishing gears used to catch turtles.
- The number of each type of gear.
- The main type of fish caught in each gear type.
- The amount of each type of fish caught.
- The average price per unit of each type of fish caught.
- The number of turtles, dolphins, dugongs and whales caught accidentally and gears responsible.
Collect reports from hospitals on:
- The number of suspected cases of turtle poisoning.
- Injuries from dynamite use.
Recruit a recorder at the main shell market areas to record:
- The average number of shells collected.
- The average size of shells collected.
- The average price of the shells.

**Tertiary data collection (questionnaires)**
Survey information would be collected from questionnaires submitted periodically to record whether any changes have been observed in the environment or in the resources of the administrative region.

The team prepared and discussed draft questionnaires to monitor pollution, coastal erosion, unsustainable use of mangroves and destructive use of resources. Two types of questionnaires are being developed: (1) for policy makers at regional, district, ward and village levels, and (2) for citizens of the community, including the direct and indirect users of the resources. The questionnaires would be applied seasonally and where possible, to the same individuals to facilitate consistency of observations.

**Proposed study areas for the three components of the plan**
The study areas have been selected in areas considered to have environmental problems and where there are possible counterpart institutions. The following fifteen (15) study areas are proposed:
1. Hale Power Station
2. Mtera Power Station
3. Tanga Port Area
4. Msimbazi Creek, Dar es Salaam
5. Kunduchi Beach, Dar es Salaam
6. Dar es Salaam Port Area
7. Bagamoyo Town, Coast Region
8. Ruvu River Mouth, Coast Region
9. Mafia Island, Coast Region
10. Menai Bay, Zanzibar
11. Matemwe, Zanzibar
12. Paje, Zanzibar
13. Port Area, Zanzibar
14. Mnazi Bay, Mtwara
15. Port Area, Mtwara

All the study areas would be examined through field sampling, secondary data collections and questionnaires except for the two power stations where only secondary data collection will be conducted. Table 4 shows the suggested sampling areas and projected items to be studied.

The third meeting, in May 1999, raised the question of whether the team had not gone too far in stripping science or scientists out of the monitoring plan and a revision
was suggested. Counter argument was that the information acquired by citizen monitoring could serve managers as well as provoke scientists to investigate the area in question. Field trials and evaluation of the data obtained will be the best way to judge the relevance. The meeting resolved to refine the plan further in 1999 before starting field work.

Table 4. Proposed study areas

<table>
<thead>
<tr>
<th>Sampling areas</th>
<th>Items to be studied</th>
<th>Possible counterparts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hale Power Station</td>
<td>Pollution</td>
<td>Hale Power Station</td>
</tr>
<tr>
<td>Mtera Power Station</td>
<td>Pollution</td>
<td>Mtera Power Station</td>
</tr>
<tr>
<td>Tanga port area</td>
<td>Erosion, pollution</td>
<td>District offices, port authority, local communities</td>
</tr>
<tr>
<td>Msimbazi Creek</td>
<td>Erosion, pollution</td>
<td>Ministries, regional and district offices, NEMC, fisheries, UDSM, local communities</td>
</tr>
<tr>
<td>Dar es Salaam port area</td>
<td>Erosion, pollution</td>
<td>Ministries, regional and district offices, port authority, local communities</td>
</tr>
<tr>
<td>Kunduchi Beach</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>TAFIRI, local communities</td>
</tr>
<tr>
<td>Bagamoyo</td>
<td>Erosion, mangroves, fisheries, destructive resource use</td>
<td>District offices, Mbageni Fisheries Research Institute, UDSM, local communities</td>
</tr>
<tr>
<td>Ruvu River mouth</td>
<td>Pollution</td>
<td>District offices, water department, Mbageni Fisheries Research Institute, local communities</td>
</tr>
<tr>
<td>Mafia Island</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>District offices, Mafia Island Marine Park, WWF, local communities</td>
</tr>
<tr>
<td>Zanzibar port area</td>
<td>Erosion, pollution</td>
<td>District offices, port authorities, IMS, local communities</td>
</tr>
<tr>
<td>Menai Bay</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>Ministries, regional and district offices, IMS, WWF, local communities</td>
</tr>
<tr>
<td>Matemwe</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>Ministries, regional and district officials, IMS, local communities</td>
</tr>
<tr>
<td>Paje</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>Ministries, regional and district offices, IMS, NGOs, local communities</td>
</tr>
<tr>
<td>Mtwarra port</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>Regional and district offices, Rural Integrated Project Support, local communities</td>
</tr>
<tr>
<td>Mnazi Bay</td>
<td>Erosion, pollution, mangroves, coral reefs, fisheries, destructive resource use</td>
<td>Regional and district officials, Frontier, local communities</td>
</tr>
</tbody>
</table>

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E: ESTABLISHMENT OF A TCMP COASTAL SCIENCE FOR MANAGEMENT WORKING GROUP

At the third and final meeting of MEAMCOT in May 1999, the structure and role of a group that would be created to replace the interim committee with a Working Group to the Tanzania Coastal Management Partnership (TCMP) was discussed. The Working Group is being created to provide a mechanism to strengthen the integration of science and coastal management. It is being created in recognition that management of complex ecosystems subject to significant human pressures requires appropriate scientific tools and sound knowledge. The sciences are vital to gaining an understanding of how ecosystems function; monitoring the conditions and trends of marine ecosystem health; unravelling the causes of specific environmental problems; and to helping find appropriate solutions to critical coastal resource management problems. Coastal management experience worldwide demonstrates that in successful programmes science has clearly defined roles in the planning, formulation and implementation of coastal management strategies.

Participants to the May 1999 meeting of MEAMCOT recommended the elements of an action plan for the TCMP Working Group on science and management. These elements include the following:

- Complete and publish the bibliographies and syntheses.
- Complete and publish the first draft of directory of coastal and marine scientists and make it available on the IMS Web site.
- Establish or strengthen local-national links and networks of existing on-going monitoring efforts through meetings and information sharing.
- Develop field sampling plans for the monitoring plan, including methodology for selecting monitoring priorities and for storing and assessing data; development of alternative models of what and how to measure and a strategy for data storage and management; review of plans by anticipated partner institutions and scientists; and pilot testing.
- Suggest strategies for a pilot nutrient monitoring initiative with a grant from the Graduate School of Oceanography, the University of Rhode Island that will yield the greatest lessons learned and that will be most relevant to critical management issues.
- Formulate a methodology for collection of secondary data for the monitoring plan, including how the data will be used, assessed and stored and a pilot test methodology in selected monitoring station(s).
- Formulate a survey methodology (including how the information will be assessed, stored and managed) for collection of information through questionnaires to villagers and local government officers for the monitoring plan.
- Seek financial resources from new and additional sources to support coastal and marine ecosystem monitoring.
Formulate a strategy for communication, publication and information dissemination.

It is expected that the first meeting of the Working Group will be in August 1999.

REFERENCES


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Restoration of coral reef and mangrove ecosystems at Kunduchi and Mbweni, Dar es Salaam, with community participation

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ABSTRACT

A baseline study was conducted on the fringing coral reef around Mbudya Island, just offshore from Kunduchi. The snorkelling visual census technique was used to estimate percentage of various types of biocover. There were substantial areas of no biocover (15–40%) which was attributed to dynamite fishing and wave action. Of the hard coral cover, which was 47% on the landward side of Mbudya and 12% on the seaward side, 40–60% was dead, probably largely due to coral bleaching. The live coral included 29 genera representing 11 families. Fish were generally more abundant on the landward side. Preliminary trials were conducted on ecosystem restoration with community involvement. Fishermen were involved in transplanting corals on the fringing reef at Mbudya Island. Approximately, 500 fragments of Galaxea sp., Acropora sp., Porites sp., and Montipora sp. were transplanted in 7 dynamited sites, using cement-filled, disposable plastic plates. Monitoring was subsequently carried out in the restored sites. Approximately 3 months after transplanting the corals, Galaxea sp. showed very significantly greater survival (100% complete survival) than Porites sp. (55.7% complete survival, 13.9% partial survival), but there was no significant difference between Acropora sp. and Montipora sp. survival. Over a period of 5 months, increase in height was significant for Galaxea sp. and Porites sp., but not for Acropora sp.

Likewise, a baseline study was conducted in Mbweni Mangrove Forest using the transect line plots method. One site near the village, which had formerly been dominated by Rhizophora mucronata, has been severely cut for firewood and building poles in recent years. It now consists mostly of saplings, dominated by Ceriops tagal (0.20 individuals/m²), followed by R. mucronata (0.10 individuals/m²). In another site, which was clear cut about two years ago, C. tagal, Avicennia marina and R. mucronata (mostly
seedlings) are now found at densities of 0.23, 0.10 and 0.01 individuals/m², respectively. Women at Mbweni Village assisted with the transplanting of more than 3000 seedlings of Rhizophora mucronata in Mbweni Mangrove Forest. This mangrove replanting activity resulted in the spontaneous formation of a new community-based organisation (CBO) known as Mbweni Environment and Women’s Group. The monitoring of mangrove seedlings showed that after 8 months, 35–38% were in perfect condition. The site that had been clear cut showed very poor seedling survival. Poor tidal inundation may be one of the main reasons for the low survival rates.

The potential for ecotourism in the area was also investigated. Of the tourists and residents of beach hotels interviewed, 92% said they would be interested in sailing to Mbudya on a traditional dhow with local fishermen. Of the villagers interviewed, 100% of those in Mbweni and most of those in Kunduchi said they were interested in participating in ecotourism.

Participatory rural appraisal (PRA) and standardised interviews undertaken in Kunduchi Fishing Village and Mbweni Village showed that these communities have low education levels, poor infrastructure, and low incomes and are largely dependent on natural resources, particularly through fisheries and agriculture. Environmental problems were also identified. The establishment of ecotourism may be a way of providing an alternative income-generating activity, while at the same time solving some of the environmental problems.

INTRODUCTION

The Dar es Salaam coast contains a variety of marine ecosystems, i.e. coral patch reefs, fringing reefs around islands, seagrass beds, mangrove forests, estuaries and sandy beaches which, in past years, have been endowed with a great diversity and abundance of marine life.

During recent decades, these ecosystems have become partially to severely degraded by various human activities such as dynamite fishing (Bryceson, 1978), beach seining, the use of small-mesh size nets (Benno, 1992), overfishing, cutting of mangroves (Wagner et al., 1999), unmanaged tourism (Wagner, 1999), boat grounding and anchoring (Kamukuru, 1997), rampant collection of ornamental corals and shells (Kayombo, 1988), sand mining and the discharge of industrial, domestic and agro-chemical wastes (Machiwa, 1992; Mashauri and Mayo, 1989). These activities have led to loss of habitat, disruption of the ecological balance of ecosystems, reduction in biodiversity, and decrease in available natural resources (Wagner et al., 1999).

In addition to the human-caused degradation, a widespread coral bleaching event occurred in 1998, related to a rise in seawater temperature and an increase in rainfall.
and a drop in seawater salinity, that was associated with the El-Niño weather phenomenon (Wilkinson, 1998; Muhando, 1999).

In badly degraded ecosystems, mere protective measures are insufficient. Active restoration is required in order to return such ecosystems to their original state in a reasonable length of time and to regain, as far as possible, the original species composition (Hunter, 1996; Wagner, 1998). Moreover, rapid restoration is necessary so as to rebuild, as quickly as possible, the natural resource base upon which the coastal communities are so much dependent.

In the case of coral reef ecosystems, several restoration techniques can be applied (Wagner, 2000). A simple technique is the physical removal of sediments, rubble, and sometimes algae from the surface of reef structures to facilitate the settlement and establishment of corals. A second method is the transplantation of coral fragments taken from healthy colonies (Guzman, 1991; Clark and Edwards, 1994). Coral fragments are stuck onto suitable substrate using cement or glue. A third method is the broadcasting of coral fragments loosely onto the substratum (Lindahl, 1998). This method can be used for transplanting large, heavy fragments in deeper sites. A fourth method is the placement or creation of artificial substrates or reef structures (Edwards and Clark, 1992; Clark and Edwards, 1994), such as concrete blocks or ceramic tiles (Nzali et al., 1998). These provide suitable substrate for the settlement and establishment of coral larvae.

Methods of restoring mangrove ecosystems include planting seedlings/saplings ranging in size from 30cm to over 3m in height, but generally the diameter at breast height (DBH) should not exceed 5cm. Planting propagules is also very effective. Propagules of *Rhizophora* spp. can be transplanted directly into the field, while for *Sonneratia* spp. and *Avicennia* spp. it is advisable to transplant them in nurseries first (Food and Agriculture Organisation, 1994).

This study was carried out at Kunduchi and Mbweni, situated approximately 20km and 30km, respectively, north of Dar es Salaam city centre (Figure 1). There are a number of coral reefs near these areas that have traditionally been important fishing grounds, but have now been largely degraded (Kamukuru, 1997; Wagner et al., 1999). The reefs off the Kunduchi coast include the fringing reefs around Mbudya and Pangavini Islands, Fungu Yasin and Fungu Mkadya patch reefs and a number of other smaller patch reefs, all of which are situated in the Dar es Salaam Marine Reserves System, gazetted in 1975 (Kamukuru, 1997). Moreover, both areas have mangrove forests that have been severely affected by overexploitation. The communities living at Mbweni and Kunduchi Fishing Village depend largely or wholly upon marine and coastal resources.

The fringing coral reef around Mbudya Island, which is adjacent to Kunduchi Fishing Village, and the mangrove forest at Mbweni Village were targeted for detailed baseline studies and restoration activities.

Qualitative, descriptive account of the distribution of coral fauna in the Dar es Salaam marine reserve system, conducted in 1974 indicated the presence of 88 species
Figure 1. Map of the coast of Tanzania in the vicinity of Dar es Salaam showing the location of the project area

belonging to 34 genera (Hamilton, 1975). The notable feature of leeward side of Bongoyo and Mbudya Islands coral fauna was the extensive coverage of *Galaxea clavus* and *Acropora formosa*, which appeared to be competing equally for domination of reef slopes (Hamilton, 1975). The two species were reported to be well adapted to high turbidity, *G. clavus* having long, numerous polyps capable of removing fine sediment from the feeding apparatus and *A. formosa* having fine, upward-pointing branches which impede the settlement of sediments.

Kamukuru (1997) conducted a study in the Dar es Salaam Marine Reserves System at two sites each on the fringing reefs of Mbudya Island and Bongoyo Island and at one site at Pangavini Island. Using the line intercept transect method (at the reef crest only) he observed that the dominant benthic category was hard coral which ranged in area cover from 34.7% on the southwest side of Bongoyo to 81.2% on the southwest side of Mbudya. The second category in importance was algal turf which ranged from 6.5% at Mbudya Southwest to 45% at Bongoyo Southwest. The third was coralline algae which was highest (17.4%) at Mbudya Northwest. Other benthic categories
(calcareous algae, fleshy algae, sand, sea anemones, seagrass, soft coral, sponge, and clams) showed low percent cover (<10%) at all sites.

Kamukuru (1997) found that, in his five sites, the dominant hard coral taxa were Acropora sp. (21.3%), Montipora sp. (18.1%), Galaxea clavus (15.2%), Galaxea fascicularis (14.9%), and Fungia sp. (13.1%). There was significant positive correlation between hard coral cover and both fish biomass ($r = 0.57$, $n = 20$, $p < 0.01$) and fish density ($r = 0.64$, $n = 20$, $p < 0.002$), but significant negative correlation between hard coral cover and both sea urchin biomass ($r = -0.68$, $n = 20$, $p < 0.001$) and sea urchin density ($r = -0.56$, $n = 20$, $p < 0.01$) as well as between sea urchin biomass and fish biomass ($r = -0.62$, $n = 20$, $p < 0.005$). Sea urchins are bioeroders due to their feeding habits and the abrasive movements of their spines during locomotion; thus, where they are numerous, they can cause significant erosion of coral reefs.

A recent ecological study of the reefs of Bongoyo, Pangavini and Mbudya Islands (McClanahan et al., 1999) indicated that the Mbudya sites have changed the least since Hamilton’s survey in 1974. Nonetheless, the Mbudya sites which were dominated by Acropora spp. in 1974 are now dominated by Montipora spp., while Acropora spp. make up only 30% of the hard coral cover. Moreover, sea urchin abundance has greatly increased (McClanahan et al., 1999).

The coral bleaching event (March to May 1998) coincided with higher-than-normal seawater temperatures and increased rainfall (lower salinity) (Muhando, 1999). Coral bleaching was reported on all parts of the Tanzanian coast with variable severity. Bleaching was worse in shallow waters (reef flats) than in deeper waters. After the bleaching event, the dead corals were colonised by filamentous algae. By November 1998, these were replaced by macroalgae and coralline algae. By January 1999, some areas showed the recruitment of small corals, while others were colonised by corallimorpharia and soft corals. On the economic side, some dive operators reported a decline in tourist potential due to the bleaching event (Muhando, 1999). There have been no previous studies on the effect of coral bleaching in the Kunduchi area.

Fishing along the Dar es Salaam coast is most frequently practised in shallow waters, particularly around coral reefs and over seagrass beds. The most commonly used gear include the hook and line, hand-woven basket traps, and nets of various types and mesh sizes. For the last 30 years, destructive fishing techniques (mainly using explosives) have been practised (Bryceson, 1978). Dynamite damage, evident at the reefs of Kunduchi, may be largely responsible for poor condition of the reefs and diminished fish catches.

The major demersal catch includes carnivores, scavengers or piscivores (Lethrinidae, Labridae, Mullidae, Lutjanidae, Haemulidae and Serranidae) and herbivores (Siganidae and Scaridae). All along the East African coast, fish reproductive activity is common during the Northeast Monsoon (Nzioka, 1979). However, some species breed throughout the year, while the blue-speckled parrotfish (Leptoscarus vaigiensis), which inhabits the seagrass beds along the Kunduchi coast, reproduces during the Southeast
Monsoon (Rubindamayugi, 1993). Benno (1992), investigating the effects of beach seine fishery at Kunduchi, showed that 50% of the catch comprised herbivorous fish (Scaridae and Siganidae). Of all the catch landed by beach seines, 51.3% was immature, 37.8% had developing gonads and only 7.8% were in spawning state. Thus, almost 90% of the beach seine catch had no chance to spawn during their life time. Benno (1992) reported that the beach seining practised at Kunduchi inhibited both growth and recruitment of fish since the seine nets used had mesh sizes not exceeding 12mm.

McClanahan et al. (1999), using the underwater visual census (UVC) technique, found that there has been a loss of keystone predator species, the triggerfish (Balistidae), which control sea urchin populations (Kamukuru, 1997). This has resulted in sea urchin proliferation, leading to their being more abundant (with an average density of 2 individuals/m² and wet biomass of 3520kg/ha) than fish (with a density of 1 individual/m² and wet biomass of 230kg/ha). Furthermore, an increase in number and species of damselfish and wrasses in the Dar es Salaam Marine Reserve System was noted (McClanahan et al., 1999), which is likely due to an indirect effect of overfishing other species.

The species composition of mangrove communities is influenced by various environmental factors. These include topography, climate, salinity, strength and direction of tidal currents, and substrate (Banyikwa and Semesi, 1986). McCusker (1975) and Semesi (1986) reported six species of mangroves at Kunduchi and Mbweni, namely, Sonneratia alba, Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza, Avicennia marina and Xylocarpus granatum. Lumnitzera racemosa is also found at Mbweni (pers. observ.).

According to Semesi (1986), in the mangrove swamp along Kunduchi Creek, Sonneratia alba, Xylocarpus granatum, and Bruguiera gymnorrhiza are less prominent than Rhizophora mucronata, Ceriops tagal and Avicennia marina. Semesi (1991) estimated the Kunduchi Mangrove Forest to cover 68.7ha. However, in recent years, this forest has been severely cut and only remnants of the original forest vegetation remains. At present, the dominant species are A. marina and C. tagal, species which are able to regenerate profusely under the prevailing level of disturbance (pers. observ.).

The mangrove vegetation at Mbweni has been far better developed and more protected than that at Kunduchi (Banyikwa and Semesi, 1986). The dominant species were reported to be Avicennia marina, followed by Rhizophora mucronata, Ceriops tagal and Xylocarpus granatum (Banyikwa and Semesi, 1986). In some parts of the Mbweni Mangrove Forest, sand deposition occurs which kills mangroves by burying pneumatophores and blocking tidal water movement (S MESI, 1991; pers. observ.). Semesi (1991) estimated a coverage of 107.3ha and reported that most of the section of Mbweni Forest near Mbweni Village was dominated by Rhizophora mucronata mixed with Avicennia marina, Ceriops tagal, Bruguiera gymnorrhiza and Sonneratia alba. In this section, stand density was estimated to be less than 50% and average stand height to be 10m.
METHODOLOGY

This study has been characterised by several important elements:
- Socioeconomic analyses of the communities,
- Baseline environmental studies,
- Community participation in mangrove and coral restoration,
- Monitoring of restored areas, and
- Preliminary investigation of the potential for ecotourism in the study area.

Socioeconomic analyses of the communities
Socioeconomic analyses of the Kunduchi and Mbweni communities was conducted through participatory rural appraisal (PRA) (involving transect walks, participatory village resource mapping, focus group discussions, and direct observation) and standardised interviews which were administered to 145 individuals.

Coral reef survey, transplanting and monitoring at Mbudya Island
The snorkel visual census technique (Darwall et al., 1997) was used to record data on habitat type (percentage of various types of biocover and non-living substrate), the distribution of coral genera, and the abundance of fish and invertebrates. On each side of the Island, 8 transects were located using systematic random sampling, each transect being 80m long and 5m wide, with a 10-m gap between them. The transects examined followed the 1.5m depth contour at time of low spring tides.

Local fishermen from Kunduchi Fishing Village were trained to carry out a low-tech method of coral transplanting while using their own dhows. They became very proficient at this exercise and worked with enthusiasm. Disposable plastic plates (16 x 22 x 3cm) were filled with cement and put into position in sites destroyed by dynamite fishing. Fragments of corals (10–15cm long for branching corals and approximately 15 x 8cm for foliaceous corals) from healthy colonies nearby were broken off and pressed into the cement in the plates (at an average of 5 fragments per plate) before it hardened.

Approximately 500 fragments (in about 100 plates) of Glaxea sp., Acropora sp., Porites sp. and Montipora sp. were transplanted in 7 dynamited sites on the northwest and southwest sides of Mbudya Island.

Approximately 3 months after the corals were transplanted, all transplanted coral fragments which could be found were examined for survival/health status. In addition, baseline data were recorded on sizes of the surviving fragments on randomly selected plates. In the case of branching and submassive corals, the length and diameter (at 2.5cm above the cement plate) were recorded; for foliose types, the height at the highest point and the diameter at the widest point were recorded. All plates were numbered to facilitate future monitoring.
Mangrove survey, replanting and monitoring at Mbweni Forest

The transect line plots method (English et al., 1994) was used to determine mangrove species composition and abundance. Three sites were selected for study within the Mbweni Mangrove Forest. One site was between Mbweni Village and the ocean where there had been severe cutting, mainly for the purpose of firewood and building poles, but there were no clear cut areas. The second and third sites were located north of the village in an area that had been clear cut for the construction of a hotel which never took place. The second site had been cut prior to the third and therefore had already begun some regeneration. The third site was still barren, for the most part, except for a few isolated trees.

Within each site, four permanent transects were established perpendicular to the shoreline. These transects were divided into zones according to tidal inundation/flooding classes and main forest types. Randomly located, 10 x 10m permanent plots were established within each forest type and marked for future monitoring. Within each permanent plot, all mangroves were identified to species level, classified according to maturity category (seedling, sapling, or tree), and counted. All stumps were also counted.

The women of Mbweni Village were trained initially to transplant newly-established mangrove seedlings. Seedlings, which were found in large numbers under mature trees were dug out and transplanted into nearby degraded or open areas of the mangrove ecosystem. Later, during the season when propagules were available, freshly fallen propagules were collected and transplanted in open areas. More than 3000 seedlings were planted in various parts of the mangrove forest, including some of the areas where permanent plots had been established. Most of the seedlings/propagules transplanted were *Rhizophora mucronata*, but a few were *Avicennia marina*.

This mangrove replanting activity resulted in the spontaneous formation of a new community-based organisation (CBO) known as Mbweni Environment and Women’s Group. The women became interested in their environment and recognised the importance of conserving it.

Monitoring was carried out three months after the first mangroves were transplanted by assessing the health of the seedlings according to four categories: perfect condition; slightly unhealthy (slightly wilted, yellow leaves or only a bud) but likely to survive; very unhealthy (no leaves or buds, stem still slightly green) but with a slight chance of survival; and dead. Soil organic matter content and saturation capacity were also measured.

Three sites were monitored. Sites A and B were near Mbweni Village where many mangroves had been cut for firewood and building poles, but there had been no clear cutting. Site A had been previously examined in the baseline study. Site C was the site examined in the baseline study which had been clear cut about two years ago.

Potential for ecotourism

Villagers as well as tourists and residents of beach hotels were interviewed using a structured questionnaire in order to determine the level of interest and preferences with respect to ecotourism in the study area.
RESULTS AND DISCUSSION

Socioeconomic analysis of the local communities

The people in the project area generally have a very low level of formal education. Based on the random sample interviewed, about one-third of the population (31%) had had no formal education at all, 26% had reached only up to Standard IV, 3% had completed Standard VII, and only about 2% had received post-primary education. Women generally had lower literacy and educational levels than men.

The primary occupations undertaken in these communities are, in order of importance, business (primarily small) (36%), fishing (22%), agriculture (19%), and quarrying (9%). The income of most people lies in the range of Tsh. 200,000–400,000 (US$ 250–500) per year, with almost equal numbers of men and women belonging to this income category. However, more women (48%) than men (37%) earn less than that, while more men (20%) than women (12%) earn more than that amount. Most interviewees said that their real income over the past 5 years (in terms of purchasing power) has dropped.

Kunduchi and Mweni communities show very high dependence on marine and coastal resources which points to the fact that conservation of the environment and natural resources in the project area is of utmost importance to the economic well-being of these coastal communities. Specifically, almost 50% of the people are directly dependent upon natural resources through fisheries and agriculture. Others depend directly or indirectly on natural resources for the operation of petty businesses; for the production of building poles from trees such as mangroves; for the production of fuel for cooking (firewood, charcoal) and for quarrying.

According to members of the communities, the major environmental problems in their area are decline in the fisheries resource base, degradation of mangrove forests, coastal erosion, decline in the terrestrial resource base (forestry, agriculture, and natural water resources), lack of a safe and sufficient water supply, poor disposal of sewage and domestic wastes, industrial pollution, and environmental health problems.

The results show that there are several socioeconomic problems in the community which are probably largely responsible for the environmental problems. Lack of education seems to be a key problem which in turn is responsible for the low income levels. Lack of education, and in particular, lack of environmental awareness have no doubt led to the inappropriate use of the environment through destructive fishing practices and excessive mangrove cutting. At the same time, low income levels have necessitated the use of environmentally unfriendly resource use practices in order to just survive for the present, regardless of the consequences for the future.

At the same time, this cause-and-effect relationship is reciprocal, i.e. the apparent drop in real income levels over the past 5 years may be attributed, at least partially, to reduction in fisheries and agricultural production due to environmental degradation.

In order for the people's socioeconomic welfare to improve, two strategies are necessary. One is to reverse the process of environmental degradation through protection
and restoration and the other is to create alternative sources of income which could relieve some of the pressure off the natural resources, particularly in the marine environment.

**Coral reef status**

Hard coral cover was found to be significantly greater on the landward side (47%) of Mbudya Island than on the seaward side (12%), while soft coral, seagrass, and algal cover were significantly greater on the seaward side (Figure 2, Table 1). This trend is probably due to the strong wave action which occurs on the seaward side making hard coral settlement and survival difficult, while at the same time creating available space for the other types of biocover mentioned.

![Chart showing biocover percentages](image)

Figure 2. Percentage of various types of biocover on the landward and seaward sides of Mbudya Island

<table>
<thead>
<tr>
<th>Biocover</th>
<th>U</th>
<th>Probability</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard coral</td>
<td>61</td>
<td>0.001 &lt; p &lt; 0.002</td>
<td>s.d.</td>
</tr>
<tr>
<td>Soft coral</td>
<td>55.5</td>
<td>0.01 &lt; p &lt; 0.02</td>
<td>s.d.</td>
</tr>
<tr>
<td>Seagrass</td>
<td>58</td>
<td>p = 0.005</td>
<td>s.d.</td>
</tr>
<tr>
<td>Algae</td>
<td>60</td>
<td>p = 0.002</td>
<td>s.d.</td>
</tr>
<tr>
<td>Sponges</td>
<td>36</td>
<td>p &gt; 0.20</td>
<td>n.s.d.</td>
</tr>
<tr>
<td>Total biocover</td>
<td>35.5</td>
<td>p &gt; 0.20</td>
<td>n.s.d.</td>
</tr>
</tbody>
</table>
The 81.2% hard coral cover observed by Kamukuru (1997) on the southwest side of Mbudya (which is also the landward side) was considerably higher than the 47% reported here. However, direct comparison is difficult for several reasons. In this study, 60% of the hard coral cover on the southwest side was alive (the rest being intact, but dead), while Kamukuru (1997) does not indicate what percentage was alive. Moreover, Kamukuru’s data were for a specific part of the landward side, while this survey covered a larger proportion of the landward side. In addition, the more accurate line intercept transect technique was used in his study, while this study used a rapid survey technique which is less accurate, but covers a larger area (Wagner, 2000). Nevertheless, it would appear that there has been a degradation of the reef over the past few years perhaps due to coral bleaching and dynamite fishing. It is also possible that the constant movement of speed boats from Zanzibar, which pass very close to the Island, has caused sedimentation on the reef.

The condition of the Mbudya reef seems to be better than most reefs in Tanga, where live coral was assessed as being about 20% (IUCN, 1987), some reefs in the Songo Songo Archipelago such as Polasi, with 25–31% hard coral cover (Darwall et al., 1996) and some reefs in Zanzibar such as Mnemba, with 13.95% cover; but poorer than other reefs in Zanzibar such as Bawe, with 53.11% cover (Muhando, 1999), most reefs in Pemba, having up to 60 or 75% cover (Horrill et al., 2000), and some reefs in the Songo Songo Archipelago, which have up to 55% hard coral cover (Darwall et al., 1996).

Of the hard coral observed, 50% on the landward side and 59% on the seaward side was dead, this difference not being significant as determined by the two-sample t-test ($t = 0.992, 0.50 > p > 0.20, \text{DF} = 14$). The death of the corals was attributed largely to the coral bleaching event of 1998 (Wilkinson, 1998; Muhando, 1999). In addition, on the seaward side, death of corals was attributed to strong wave action and current flow which not only breaks the corals, but also stirs up sediment particles, creating turbidity which blocks light and clogs the feeding apparatus of the coral polyps (Wagner et al., 1997).

With respect to the living hard coral, a total of 29 genera belonging to 11 families were observed, 26 on the landward side and 23 on the seaward side (Table 2). The most commonly observed corals on the seaward side were bommies of *Porites* and *Platygryra* and short, thick-branched *Acropora*; while, on the landward side, delicately branched *Acropora*, and foliose *Montipora* were common, together with *Echinopora*, *Galaxea*, *Goniastrea* and *Porites*.

It would appear that diversity, in terms of number of genera, has probably not changed substantially since the study by Hamilton (1975), since he found 34 genera on the five reef sites in the Dar es Salaam Marine Reserve System, while 29 genera were found in this study on the fringing reef of Mbudya alone. However, his study did not give any measure of the evenness component of diversity with which to make comparisons. The observed preservation of genera over time is consistent with the
Table 2. Distribution of coral genera on the fringing reef of Mbudya Island

<table>
<thead>
<tr>
<th>Coral genus</th>
<th>Family</th>
<th>Landward</th>
<th></th>
<th>Seaward</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>North</td>
<td>South</td>
<td>North</td>
<td>South</td>
</tr>
<tr>
<td><em>Acropora</em></td>
<td>Acroporidae</td>
<td>Pa</td>
<td>Pa</td>
<td>Pa</td>
<td></td>
</tr>
<tr>
<td><em>Astreopora</em></td>
<td>Acroporidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Aveopora</em></td>
<td>Poritidae</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Coccoceros</em></td>
<td>Agaricidae</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cycloceros</em></td>
<td>Fungiidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Diploastrea</em></td>
<td>Faviidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><em>Echinopora</em></td>
<td>Faviidae</td>
<td>Pa</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Favia</em></td>
<td>Faviidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Funga</em></td>
<td>Fungiidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Galaxea</em></td>
<td>Oculinidae</td>
<td>P</td>
<td>Pa</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Goniastrea</em></td>
<td>Faviidae</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Herpolitha</em></td>
<td>Fungiidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Hydnophora</em></td>
<td>Faviidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Leptastrea</em></td>
<td>Faviidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Leptoria</em></td>
<td>Faviidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><em>Millepora</em></td>
<td>Milleporidae</td>
<td>P</td>
<td>Pa</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Montastrea</em></td>
<td>Acroporidae</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Montipora</em></td>
<td>Acroporidae</td>
<td>P</td>
<td>Pa</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><em>Pachyseris</em></td>
<td>Agaricidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><em>Pavona</em></td>
<td>Agaricidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Platygyra</em></td>
<td>Faviidae</td>
<td>Pa</td>
<td>Pa</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Porillopora</em></td>
<td>Pocilloporidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Porites</em></td>
<td>Poritidae</td>
<td>Pa</td>
<td>Pa</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><em>Psammocora</em></td>
<td>Thamnasteriida</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Seriatopora</em></td>
<td>Portitidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Stylophora</em></td>
<td>Portitidae</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><em>Tubipora</em></td>
<td>Tubiporidae</td>
<td></td>
<td></td>
<td></td>
<td>P</td>
</tr>
<tr>
<td><em>Tubinaria</em></td>
<td>Dendrophylliidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P = present; Pa = present in abundance

findings of McClanahan et al. (1999) who, re-visiting the five reef sites studied by Hamilton (1975), found that, although there was a loss in coral cover and an alteration in species composition over the 22-year period, there was no loss of species.

The percent total biocover was similar on both sides of the Island (Figure 2), ranging from 15–45% in the different transects. The areas with no biocover were assessed to have been damaged by dynamite fishing and wave action.

The abundance of 10 common species of fish was determined. The purple butterflyfish (Chaetodon trifasciatus) and spotted butterflyfish (C. guttatissimus) were the most abundant reef fish around the island. There was significantly greater abundance of the threadfin butterflyfish (C. auriga) (Mann-Whitney U test: $U = 64.5, p < 0.001, n_1 = n_2 = 8$), the Goldring bristletooth (Ctenochaetus strigosus) ($U = 61, 0.001 < p < 0.002, n_1 = n_2 = 8$), and the brushtail Tang (Zebrasoma scopas) ($U = 66, p < 0.001, n_1 = n_2 = 8$) on the landward side than on the seaward side, which may be attributed to the landward
side having a greater percent cover of hard coral and relatively less destruction by dynamite fishing. Only the masked bannerfish (*Heniochus monoceros*) was significantly more abundant on the seaward side \((U = 53, 0.02 < p < 0.05, n_1 = n_2 = 8)\).

There was a significantly greater abundance of bivalves on the landward side than on the seaward side (two-sample t test: \(t = 3.686, 0.002 < p < 0.005, \text{DF} = 14\)), but more sea cucumbers on the seaward side, associated with the extensive seagrass beds found there \((t = -2.68, 0.01 < p < 0.02, \text{DF} = 14)\). There was no significant difference in abundance of the other groups on the two sides of the island, though there was a high concentration of sea urchins (particularly *Diadema* spp.) in the seagrass beds on the southern portion of the seaward side.

This study showed that, in 1999, there were 0.9 sea urchins per 10m\(^2\) on the northwest side of Mbudya, while Kamukuru (1997) reported that there were 20.8 urchins/10m\(^2\) in 1996. Moreover, on the southwest side, this study showed there were 1.0 urchins/10m\(^2\), while Kamukuru’s study showed there were 9.6 urchins/10m\(^2\). Thus, over the 3-year period, there seems to have been a substantial reduction in sea urchin abundance. Possibly there has been a recovery in the abundance of the keystone predator species, the triggerfish (*Balistidae*), though no data were collected in this study which could substantiate this argument.

**Coral transplants**

Of the approximately 500 coral fragments transplanted, 342 fragments were found and their survival rates/health status recorded as shown in Table 3. *Galaxea* sp. showed very significantly greater survival (100% complete survival) than *Porites* sp. (55.7% complete survival, 13.9% partial survival) \((\chi^2 = 37.010, p < 0.001, \text{DF} = 2)\), but there was no significant difference in survival between *Acropora* sp. and *Montipora* sp. \((\chi^2 = 2.200, 0.50 > p > 0.25, \text{DF} = 2)\).

Survival was independent of orientation to the island, i.e. northwest or southwest \((\chi^2 = 1.560, 0.50 > p > 0.25, \text{DF} = 2)\), but there was a very significant difference in survival rates of coral fragments among specific dynamited sites \((\chi^2 = 41.024, p < 0.001, \text{DF} = 8)\). This difference appeared to be related to depth, with greater survival occurring at greater than 1m (during low tide).

### Table 3. Survival rates/health status of various coral genera 3 months after transplanting

<table>
<thead>
<tr>
<th>Genus</th>
<th>Complete survival (%)</th>
<th>Partial survival (%)</th>
<th>Dead (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Porites</em> sp.</td>
<td>55.7</td>
<td>13.9</td>
<td>30.4</td>
</tr>
<tr>
<td><em>Montipora</em> sp.</td>
<td>76.6</td>
<td>16.7</td>
<td>6.6</td>
</tr>
<tr>
<td><em>Acropora</em> sp.</td>
<td>74.6</td>
<td>8.0</td>
<td>17.4</td>
</tr>
<tr>
<td><em>Galaxea</em> sp.</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Complete survival = entire fragment survived/alive; partial survival = some portions of the fragment are alive, others are dead; dead = entire fragment is dead.
After another 5 months (i.e. 8 months after transplanting), survival rates were nearly the same (Table 4). Some of the differences, e.g. the lower percentage of dead *Porites* sp. after 8 months than after 3 months, are due to the fact that different random samples of fragments were measured. From the third month to the eighth month, there was a significant increase in height of *Galaxea* sp. \((p < 0.0005)\) and *Porites* sp. \((0.005 < p < 0.01)\), but not of *Acropora* sp. \((p > 0.05)\).

<table>
<thead>
<tr>
<th>Genus</th>
<th>Complete survival (%)</th>
<th>Partial survival (%)</th>
<th>Dead (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Porites</em> sp.</td>
<td>90.0</td>
<td>6.7</td>
<td>3.3</td>
</tr>
<tr>
<td><em>Montipora</em> sp.</td>
<td>66.7</td>
<td>0.0</td>
<td>33.3</td>
</tr>
<tr>
<td><em>Acropora</em> sp.</td>
<td>77.0</td>
<td>8.0</td>
<td>15.0</td>
</tr>
<tr>
<td><em>Galaxea</em> sp.</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Complete survival = entire fragment survived/alive; partial survival = some portions of the fragment are alive, others are dead; dead = entire fragment is dead.

It is apparent that survival and growth rates vary from one species to another. Of the species tested in this study, *Galaxea* sp. showed by far the best survival rate and the most significant growth. Franklin et al. (1998), growing coral fragments on racks at Chumbe Island Coral Reef Sanctuary, Zanzibar, found that the weight increases of 5-cm fragments after 1 year were 13, 23, and 54% for *Pocillopora verrucosa*, *Porites cylindrica*, and *Acropora nasuta*, respectively, again showing considerable differences among species.

Probably the main reason for poorer survival of transplants in shallow sites \((< 1m)\) is that wave action turned over some of the plates causing either breakage of the corals or death of the portions of the fragments which faced downwards. This problem could be overcome by cementing the plates onto the reef as soon as possible after transplanting.

In general, however, the results show that the method of coral transplantation used in this pilot study could be an effective way of restoring damaged portions of coral reefs, though other methods of restoring reefs have also been shown to be effective. Lindahl (1998) used another low-tech, low-cost method of transplanting staghorn corals (*Acropora formosa*) at Tutia Reef in Mafia Island Marine Park, Tanzania, by both broadcasting coral fragments unattached and attaching fragments by tying them together with string. At a transplanting density of 10–15%, the unattached and tied fragments showed relative increases in cover of approximately 35% and 125%, respectively, over a period of 23 months.

Another restoration method tested in Tanzania is the placement of clay tiles to enhance coral larval settlement on damaged areas of reefs. To maximise the effectiveness of this method, tiles should be placed on reefs during the period of highest coral recruitment, which was found to be during April in Tanga (Nzali et al., 1998) and during February–April.
and November–December in Zanzibar (Franklin et al., 1998). This is probably the most suitable method in areas where coral cover is not sufficient to allow for the removal of coral fragments for transplanting, but is sufficient for coral larval dispersion.

**Mbweni mangrove forest status**

The site nearest the village, which had formerly been dominated by *Rhizophora mucronata*, was found to consist mostly of saplings, dominated by *Ceriops tagal* (0.20 individuals/m²), followed by *R. mucronata* (0.10 individuals/m²), and *Avicennia marina* (0.02 individuals/m²). The site which had been clear cut several years ago was found to be dominated by seedlings and saplings of *C. tagal* (0.52 individuals/m²), followed by *R. mucronata* and *A. marina* (0.11 and 0.04 individuals/m², respectively). In the third site, which had been clear cut about two years ago, *C. tagal, A. marina* and *R. mucronata* (mostly seedlings) are now found at densities of 0.23, 0.10 and 0.01 individuals/m², respectively. In addition, there were 0.32 stumps/m².

Though it is difficult to make direct comparisons with the work of Semesi (1991) which was done through aerial photography, there appears to have been substantial degradation of the forest since that time. In this study, very few trees were observed to have reached 10m in height, which was reported to be the average stand height in Semesi’s study of photographs taken in 1989. It is obvious that there has been heavy cutting pressure during the past decade, particularly of the popular *Rhizophora mucronata*, which has resulted in a great reduction in tree biomass and a shift in species composition, with seedlings and saplings of the fast-regenerating species, *Ceriops tagal*, now dominating.

Interviews with the villagers indicated that the main reasons for cutting mangroves are for use as firewood (mentioned by 25% of the interviewees), followed by clearing for building sites and commercial projects (19%), construction poles (16%), and charcoal-making (12%). *Rhizophora mucronata* makes very good firewood and excellent building poles (Semesi, 1991) which resist rotting and thus this species has been cut more than others.

**Mangrove transplants**

It was found that 19–59% of the *Rhizophora mucronata* seedlings were in the first two health status categories (perfect condition or slightly unhealthy) (Figure 3). There was a significant difference in overall health status among sites (Kruskal-Wallis test: $H = 6.417, 0.02 < p < 0.05, k = 3$). Seedling health status was significantly better in Site A than in Site B (Dunn’s multiple comparisons test: $Q = 4.69, p < 0.001$), which was attributed to the fact that inundation of seawater is less in terms of volume in the latter. Seedling health status was significantly poorer in Site C than in either Site A ($Q = 11.05, p < 0.001$) or Site B ($Q = 6.71, p < 0.001$). Site C appeared to be a harsh environment for seedlings, with 71% being dead, probably due to its soil having the lowest organic matter content and lowest saturation capacity and due to the area having extreme exposure to sun. There is a lack of mangrove canopy cover and thus tidal water dries quickly after
Figure 3. Survival and health status of transplanted seedlings of *Rhizophora mucronata* three months after transplanting. (status 1 = perfect condition; 2 = slightly unhealthy, but likely to survive; 3 = very unhealthy, but a slight chance of survival; 4 = dead)

ebbing. In general, Site C appears to be poor for seedling survival, because the fact that it was clear cut has probably changed its environmental characteristics.

After another 5 months (8 months after transplanting), the mangrove seedling survival/health status was again assessed, but only in Sites A and B (Figure 4). Many of the seedlings that had been in the middle categories of health status 5 months earlier (slightly or very unhealthy) either attained perfect condition (35% in Site A, 37% in Site B) or died (45% in Site A, 48% in Site B). However, the difference in overall health status between the two sites became insignificant (Mann-Whitney U test: U = 11, p > 0.20). Subsequent qualitative observations indicate that most of the seedlings that survived the initial stress are still surviving and growing well.

There are two possible reasons for the low survival rates. One is that water movement in and out of Mbweni Mangrove Forest is poor and, in fact, seems to have gotten worse over the past few years (pers. observ.) though no concrete data have been recorded to verify this. There is no daily tidal movement. Seawater inundates only during spring tides and much of it drains just a few days after spring tides, leading to desiccation of the soil for much of the monthly cycle. Another reason is that the transplanting was done by villagers, and although there was supervision, sometimes there was damage of seedling roots during transplanting and some seedlings were transplanted in inappropriate zones. Nonetheless, the advantages of working with villagers is that it provides a large labour force at almost no cost and it gives the
villagers a feeling of stewardship, such that they will subsequently make efforts to protect the forest.

Although survival rate was low, since more than 3000 seedlings have been transplanted, probably at least 1000 seedlings survived in perfect condition. As these continue to grow, they will undoubtedly make a substantial impact on the overall health of the mangrove forest and are likely to improve the environmental conditions of the ecosystem. Therefore, this mangrove replanting exercise conducted by the villagers should be very much encouraged. Such replanting efforts, if accompanied by measures to hinder cutting, may well result in complete restoration of Mbweni Mangrove Forest.

However, in order to improve the future effectiveness of mangrove restoration in the area, step-by-step efforts are required to return to the natural assemblage of structure and function that will make the ecosystem self-sustaining (Kaly and Jones, 1998).

Potential for ecotourism

Of the tourists and residents of beach hotels interviewed, 92% said they would be interested in sailing to Mbuuya on a traditional dhow with local fishermen and 15% said they would be interested in watching and/or learning about coral transplantation. The tourists were also interested in snorkelling, fishing, and sporting events as well as in buying carvings, shells and handicrafts. Some, however, said that they would not want to buy shells since this would cause depletion of living organisms.

Of the more than 60 villagers interviewed, 100% in Mbweni and most of those in Kunduchi said they were interested in participating in ecotourism. They said that the attractions in their area which would likely be of interest to tourists include coral reefs,
mangrove forests, beaches, handicrafts, traditional songs/dances, shells, schools and community activities. The Mbweni villagers stated that what needs to be done in their area in order to prepare for tourists is to plant more mangroves (stated by 68% of the interviewees), to stop the cutting of mangroves (stated by 8%) and to build a boardwalk through the mangrove forest (stated by 24%). Facilities required, according to the highest number of interviewees, are a restaurant, a guesthouse, and a reliable water supply.

Ecotourism, whereby local communities are involved in guiding tourists through the attractive ecosystems in their areas and in making accompanying efforts to conserve or improve the environment, is increasingly becoming known as an important economic venture for villagers. One example is the construction of a boardwalk through the Jozani-Pete Mangrove Forest which has enabled villagers in the area to benefit from tourism (Jozani-Chwaka Bay Conservation Project, 1997).

In the Dar es Salaam area, tourism has so far been the conventional type with almost all benefits going to hotel owners, tour operators, and dive centres and very little, if any, going to people in the local communities (Wagner et al., 1999). Efforts should now be made to establish ecotourism which promotes environmental conservation and the involvement of the local communities (Dimanche and Smith, 1996).

Kunduchi fishermen offering tourists a dhow ride to an offshore island (e.g. Mbudya) and an opportunity for them to witness and/or participate in coral transplantation could be an economically viable project. The going price for a half-day trip to Mbudya is about US$10 per person, an amount which would be acceptable daily pay for one fisherman, according to informal interviews with Kunduchi fishermen. Thus, a group of 10–15 tourists would provide more than sufficient payment for a group of 5–10 fishermen to undertake this alternative income-generating project. Such a project would provide the fishermen with a supplementary source of income, reduce the fishing pressure in the area, and motivate the fishermen to protect their reefs from dynamite fishing as well as to actively restore the reefs through coral transplanting.

Mbweni is ideal for the establishment of ecotourism, particularly since there is so far no tourist hotel in the area. A full-day tour of the area could include a walk through the mangrove forest (particularly if a boardwalk could be constructed), a dhow ride and visit to offshore coral reefs, swimming and sun-bathing on the beautiful sandy beach, observation of the newly-established seaweed farm, cultural music and dancing, a tour of the village, and purchase of artefacts.

Both conventional tourism and ecotourism are potentially important income-generating activities. However, if unplanned and uncontrolled they can create many complex problems leading to serious negative impacts on the environment, which are often long-term. Thus, the development of beneficial tourism requires wise multi- and cross-sectoral management (Muruke et al., 1999).
CONCLUSIONS AND RECOMMENDATIONS

The baseline studies reported in this paper have shown that the coral reef fringing Mbudyia Island has been badly damaged by both human activities, particularly dynamite fishing, and a natural phenomenon—coral bleaching. The mangrove forest near Mbweni has been badly degraded by harvesting for firewood and building poles and by clear cutting of some areas for commercial projects.

The coral transplanting and mangrove planting techniques used in this project proved to be reasonably satisfactory, though alternative or improved techniques could be tested. Moreover, the villagers in the area showed that they are willing and able to carry out the restoration activities with guidance from scientists.

Whereas the coastal and marine environment of Dar es Salaam has been largely neglected and mismanaged, it can and should, in fact, be developed into an attractive example of conservation — the pride of the country. This is due to its proximity to a wealth of scientific and environmental expertise and is also perhaps to it being the most readily accessible natural beauty spot for the multitude of visitors and tourists that come to Tanzania.

The following recommendations can be made regarding further activities in the Kunduchi/Mbweni area:

- Studies should be undertaken in the Mbweni Mangrove Forest concerning changes in water movement over time. If sanding up of water inlets is occurring, either from natural or human causes, steps should be taken to rectify the situation; otherwise, the whole forest will be endangered.
- Future activities in Kunduchi should include restoration of the severely degraded mangrove forest along the nearby Kunduchi Creek, while activities in Mbweni should include restoration of nearby coral reefs.
- Appropriate steps should be taken to stop the cutting of mangroves and the use of destructive fishing methods, perhaps by setting up community-based patrols.
- Immediate steps should be taken to establish ecotourism in both Kunduchi and Mbweni since all the important ingredients are available in these locations, i.e. an adequate number of tourists, attractive ecosystems (pending some restoration work), and local communities who are willing to participate in this alternative income-generating activity.

Based on experience gained in this research project, several general recommendations can be made for integrated coastal management (ICM) projects/programmes in the East African region. These are:

1. Future ICM projects/programmes should combine the following elements:
   - participation of local communities in the application of already developed techniques in restoration and conservation,
   - monitoring the success of the restoration/conservation efforts,
– research into improving techniques,
– ecotourism (where feasible), and
– enhancement of environmental awareness amongst local community members and tourists.

2. Monitoring should not only be conducted by scientists, but should include citizen monitoring. Scientists should work with villagers and train them to gradually take over most of the monitoring work in a simplified form, though scientists should continue to be involved as advisors and to monitor aspects which require specialised expertise.

3. The local communities, who are in fact the primary and customary stakeholders of their surrounding natural resources, must be involved in conservation and restoration work and must be empowered to manage their coastal environment.

4. Ecosystem restoration work can be combined with ecotourism such that members of the communities receive payment from the tourists for guided tours to coral reef and mangrove ecosystems while restoration activities are carried out.

5. Ecotourism can be used as a management tool to provide motivation and financial rewards for villagers participating in environmental work. Thus, ecotourism can simultaneously lead to the economic wealth of the community and improvement of the environment.

ACKNOWLEDGEMENTS

We would like to express great appreciation to African Development Foundation for funding the socioeconomic analysis and ecosystem restoration activities, the School for International Training for funding the studies on ecosystem monitoring and ecotourism potential, Sida/SAREC for student support and the University of Dar es Salaam for equipment and the participation of staff and students. We also express our deepest gratitude to Marine Action Conservation Tanzania (MAC T) for providing inspiration and impetus for the work undertaken in this study.

REFERENCES


Gear selectivity for three by-catch species in the shallow-water shrimp trawl fishery at the Sofala Bank, Mozambique

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ABSTRACT

The reduction of shrimp by-catch when fishing with shrimp trawlers can constitute a strategy to minimise discards. A research cruise was conducted in February 1995 in shallow waters off Sofala Bank, Mozambique to investigate the sorting (selection) efficiency of cod-ends (55mm and 60mm meshes) compared to the top-grid (14mm space bar) systems using covered cod-end method. The selectivity parameters were obtained for _Otolithes ruber, Johnius dussumiarius_ and _Thryssa vitrirostris_ through the maximum likelihood estimate (MLE) method, using logit function and pooled samples through the variance component model (VCM). The top-grid was mounted at a theoretical angle of 33°, one metre aft of the retriever strap, in a downward direction. The overall shrimp to by-catch ratio was 1:1.7. On average, the cod-end selection system gave a smaller L_{50%} and wider selection range than the top-grid for all three species. According to the study, the top-grid had better selection properties than the cod-ends relative to the species mentioned above. Differences in the selectivity of 55mm, 60mm meshes and 55mm mesh combined with grid are discussed as well as cod-end and grid selection systems.

INTRODUCTION

The discard by shrimp trawlers in tropical shallow waters is particularly extensive with shrimp to by-catch ratios ranging from 1:3.3 to 1:19.4 (e.g. Mahika, 1992; Nkondokaya, 1992; Evans and Wahju, 1996; Baio, 1996; Alverson, 1998; Brewer et al., 1998). The high discard gives a negative image of this sector of the fishing industry. The issue of selectivity of shrimp fishing gear is therefore of special importance as it constitutes the most important tactic to reduce the problem (Thorsteinsson, 1992; Broadhurst and Kennelly, 1994; Anon, 1996a; Rogers et al., 1997; Brewer et al., 1998; Kennelly et al., 1998). It is against this background that the present study of by-catch in the shrimp fishery in Mozambique was conducted.

Presently the shrimp resource is the most economically important in Mozambique in terms of annual export earnings and value of the fish exports. Nevertheless, there
are enormous quantities of non-target species and sizes (by-catch) caught during shrimp fishery. Therefore, it is quite difficult to regulate selectivity for all species through the minimum mesh size of the cod-ends.

Two species, *Penaeus indicus* (Indian white prawn) and *Metapenaeus monoceros* (speckled shrimp) are the most abundant in Mozambican catches and account for more than 80% of the total yearly shrimp catches. Other species are *Penaeus japonicus* (kuruma prawn), *Penaeus monodon* (giant tiger prawn) and *Penaeus latisulcatus* (western king prawn). *Caridea* species also appear in the catches in small proportions (Brinca and Sousa, 1984). The most abundant fish species in the shrimp fishery are *Sardinella, Thryssa, Otolithes, Johnius* and *Thrichiurus* (Gislason, 1985; Bianchi, 1992; Pacule and Baltazar, 1995).

Although studies conducted before 1992 in Mozambique, were not focused on size selectivity, attempts to understand and reduce the problem date from the early 1980s. Studies were carried out to determine species composition and estimate the by-catch proportions. Pelgröm and Sulemane (1982) refer to a shrimp to by-catch ratio of 1:3 (catch rates greater than 50kg/h), Gislason (1985) found 1:3.8, Anon (1994b) found 1:5 with 89% of the by-catch discarded, and Pacule and Baltazar (1995) found 1:4.3.

There has been a need to improve the size selectivity for shrimps in the industrial shallow water fishery as emphasised in 1991 (Sætersdal, 1995). As a follow up of the selectivity experiments in shallow water prawn-trawls in Tanzania (Mahika, 1992), a similar study was conducted for industrial shallow water shrimps in Mozambique in 1993 (Isaksen and Larsen, 1993). The latter experiment showed improvement on size selection of shrimps using a top grid with 14mm bar spacing mounted in a 55mm cod-end compared to a 60mm cod-end.

Apart from these studies, the minimum legal mesh size was increased from 45 to 60mm in 1994. This increase prompted the claim from the fishing industry that they were losing at least 20 to 30% of the catches of marketable shrimp when using a 60mm cod-end mesh size (Isaksen et al., 1995). For this reason, and based on previous tests, an experiment on selection of shrimp using: (a) 55mm mesh cod-end; (b) 60mm mesh cod-end, and (c) 55mm meshed cod-end with a 14mm grid bar spacing was done in 1995. The top-grid gave better results in sorting out small-sized shrimp and at the same time retaining marketable sizes better than the cod-ends tested (Isaksen et al., 1995). To avoid making use of grid compulsory, the State Secretariat of Fisheries (SEP) approved the use of 55mm mesh as the minimum legal mesh size (Anon, 1996b). No analysis of the selectivity of by-catch species was done as part of this experiment.

Fish is the major part of the catches and the high by-catch taken in the course of shrimp fishing causes concern (Anon 1994a). However, there are logistical (e.g. limited chill or cold storage capacity), economic (e.g. low price paid for by-catch) and other factors that make the handling of non-target species difficult for the fishing industry (Suluda, 1997). Nevertheless, the by-catch species have significant importance to the country in terms of human consumption (Anon, 1994a). Therefore, it is important to
determine how different mesh sizes and the use of selective devices (grid) affect the selection of the more frequently occurring by-catch species (*Otolithes ruber, Johnius dussumieri* and Thryssa vitrirostris).

The present study was aimed at performing an analysis of by-catch data collected during the selectivity experiments in 1995. The more specific objectives are first, to quantify the by-catch composition; second, to investigate the cod-end mesh selectivity for 55mm and 60mm meshes; and third, to study the efficiency of the sorting grid as an excluder device for non-target species.

**MATERIALS AND METHODS**

The commercial shrimp trawler *ARPEM IV* was used for the investigation. The vessel was equipped with two 11.5m outriggers (Figure 1) and was able to tow two identical trawls simultaneously (Isaksen et al., 1995).

The fishing trials were done along the Sofala Bank, (19° 20' S, 35° 40' E) and along the banks further north to the area outside Angoche (16° 10' S, 39° 50' E) (Figure 2). The depth range was between 10 and 26m. All hauls were made during daytime hours. Tow duration varied between 2 and 3 hours per haul and the towing speed was 3.2 knots.

The trawls used were of the ‘semi balloon-type’, built as 4-panel trawls. A pair of wooden otter-boards were connected to each of the trawls through bridles, and to the towing warp by a 60m crowfoot. The normal warp length to depth-ratio used during the study was:

\[
\text{warp-length} = 3 \times \text{depth (fathoms)} + 25 \text{ fathoms} \quad (1 \text{ fathom} = 1.82 \text{m}).
\]

Studies were carried out applying cod-ends with 55 and 60mm mesh sizes. They had a circumference of 200 meshes and a length of approximately 5m. Both cod-ends were made of polyamide (PA). A shark protection net made of polyethylene (PE) was mounted around the cod-end. The protection net had a mesh size of 70mm and a circumference of 150 meshes. It covered the whole cod-end, and ended about 70cm aft of the cod-end knot (‘zipper’). It was open at the aft end.

The ‘twin trawl method’, whereby the two identical trawls are fished with the same cod-end mesh size, but with a small-meshed cover over one of the cod-ends, was used to investigate cod-end selectivity (Anon, 1996c). The cover had a mesh size of 37mm and a circumference of 480 meshes, giving a stretched circumference of approximately 1.5 that of the cod-end (Pope et al., 1975). The length of the cover was 6.65m and it was attached 4.65m in front of the aft end (zipper). The same cover was used for both the 55 and 60mm cod-ends and attached the same way. The shark protection net was fitted outside the cover.

The top-grid experiments were carried out with a grid with 14mm bar-spacing. The grid-section was installed about 1m aft of the retriever strap, and mounted at a theoretical
Figure 1. Schematic diagram of a shallow water shrimp trawler at the Sofala Bank, Mozambique

angle of 33° (Figure 3). The grid was made of sea-water resistant aluminum and had a length and width of 1.5 and 0.9m, respectively (Isaksen and Larsen, 1993). It weighed approximately 11kg in water. To make the top-grid neutral or slightly buoyant, 4 x 200mm plastic floats were attached to the upper and foremost part of the grid. A fine-meshed top-cover (control bag) 12.5m long and made of stretched 37mm mesh netting (Isaksen and Larsen, 1993) was placed over the escape area of the grid to collect the shrimp and fish escaping through the grid (Figure 4). A shark protection net was mounted over the aft end of the cover. The grid was used in combination with a 55mm meshed cod-end with
shark protection net, but without cover. During operation, the catch is led towards the grid sorting surface; small-sized shrimps and fish are filtered through the grid and into the control bag, whereas larger shrimp and fish are guided along and under the grid and into the main cod (Figure 5).

**Experimental set-up**

Before the experiment started, four hauls were performed to test for possible differences in fishing power between the two trawls. During the experimental fishing four groups (I,
II, III and IV) of hauls were accomplished (Table 1). In group I (hauls 1 to 10), the port and starboard sides were both rigged with 55mm meshed cod-ends (54mm nominal mesh opening), but with a fine meshed cover around the starboard cod-end. The design of experimental group II (hauls 11 to 20) was identical to that of group I, but with a cod-end mesh size of 60mm. In group III (hauls 21 to 28), port side trawl was rigged with the grid-section (including the cover above the grid) and 55mm meshed cod-end. The starboard side was rigged with a 60mm meshed cod-end with a fine-meshed cover. In group IV (hauls 29 to 32) the trawls were rigged as in commercial fishing with mesh sizes of 55 and 60mm on the port and starboard sides respectively.

<table>
<thead>
<tr>
<th>Group</th>
<th>Hauls</th>
<th>Port side</th>
<th>Starboard side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cod-end mesh size (mm)</td>
<td>Cover (37mm)</td>
</tr>
<tr>
<td>I</td>
<td>1–10</td>
<td>55</td>
<td>not used</td>
</tr>
<tr>
<td>II</td>
<td>11–20</td>
<td>60</td>
<td>not used</td>
</tr>
<tr>
<td>III</td>
<td>21–28</td>
<td>55+grid</td>
<td>used</td>
</tr>
<tr>
<td>IV</td>
<td>29–32</td>
<td>55</td>
<td>not used</td>
</tr>
</tbody>
</table>
Sampling
For each haul the catch of cod-ends and cover(s) were kept separately. The catch of the cod-end or cover was weighed and a sub-sample of two boxes (approximately 40kg each) was sorted into species groups. The species identification was made using manuals by Anon (1984); Smith (1986) and Fisher et al. (1990). The weight and number of the species in the sub-samples were recorded, and for all specimens of *O. ruber*, *J. dussumieri* and *T. vitrirostris* total length was also measured. Overall catch in weight and number of a species were determined by raising the sub-sample figures by the ratio of total weight to sub-sample weight.

Data analysis

Weight-related data analysis
Due to variation in tow duration, catches were standardised into hourly values. The by-catch proportions by weight were calculated as:

$$BCP = \frac{\sum_{i=1}^{n} BC_i}{\sum_{i=1}^{n} TC_i} \times 100$$

where $BCP$ is the by-catch proportion; $BC_i$ the by-catch weight in haul $i$; $TC_i$ the total catch (shrimp and by-catch) in haul $i$; and $n$ is the number of hauls. The confidence limits were obtained from bias and acceleration corrected (Bca) bootstrap estimates using 5000 iterations (Efron and Tibshirani, 1993). The calculation was done using the ‘bootstrap’ and ‘limits.bca’ functions in S-Plus (S-Plus ver. 4.5, Mathsoft Inc., Seattle, USA).

Variation in by-catch rates with respect to depth, time of the day and latitude were examined. The degree of association between proportion of shrimp and by-catch excluded and the total catch rates were analysed through simple linear regression analysis (Zar, 1984). To test for a possible masking effect (the effect whereby the cover around the cod-end prevents or deters fish from escaping through the meshes of the cod-end), the weight of shrimp and by-catch in the cod-ends on port and starboard sides were compared for the hauls of groups I and II (Table 1). The null-hypothesis of no difference was tested using a two-sample randomisation test for pairwise comparisons (Manly, 1991), using 5000 iterations.

Length-related data analysis
The length related data analysis involved the construction and comparison of length frequency distributions and the estimation of selectivity curves for the three species *O. ruber*, *J. dussumieri* and *T. vitrirostris*. The null-hypothesis of no difference in the length composition in the cod-end and cover was tested using a randomisation test. The difference between 55mm with grid and 60mm cod-end without grid was tested. The test was done with the actual (non-scaled) length measurements. P-values were based on 5000
permutations using the Kolmogorov-Smirnov test statistic which examines the largest absolute difference between the two cumulative frequency distributions (Zar, 1984).

\textit{Estimation of selectivity parameters}

The estimated selectivity parameters were \( L_{25\%} \), \( L_{50\%} \) and \( L_{75\%} \) (length of fish that has a 25\%, 50\% and 75\% probability of being retained after entering the cod-end, respectively) and SR (selection range, i.e. the difference between \( L_{25\%} \) and \( L_{75\%} \)). The selection factor, SF, is given by:

\[
SF = \frac{50\% - \text{retention-length}}{\text{Mesh-size} - (\text{Grid-bar-distance})} \tag{2}
\]

The cod-end and grid selectivity is represented here by reference to the 50\% selection length and SR (Pope et al., 1975; Sparre and Venema, 1992; Anon, 1996c).

Covered cod-end method was used to obtain selectivity parameters of the three species by using the variance component analysis (VCA) option which accounts for the variability between hauls and the samples (hauls) are analysed individually (Fryer, 1991). The confidence bands for the estimates are also given.

Where a masking effect was present, selectivity was also calculated using the trouser trawl method (considering the pooled numbers of each side of the trawl separately, Anon, 1996c). The computer program CC Selectivity (1995 release, ConStat, 9800 Hjoerring, Denmark) was used to solve the maximum-likelihood equation, calculate the parameters including 95\% confidence limit (Sokal and Rohlf, 1995) and fit the selectivity curves. The selection curves plotted in this paper were obtained using the maximum likelihood estimates (MLE) of the parameters from CC-selectivity applying the model (Anon, 1996c):

\[
S_L = \frac{1}{1 + \exp(-S1 - S2 \times L)} \tag{3}
\]

where \( S_L \) is the ratio between the number of fish of length ‘L’ in the cod-end and sum of number of fish of length ‘L’ in the cod-end plus in the cover; \( L \) is the length interval midpoint; \( S1 \) and \( S2 \) are constants [Paloheimo and Cadima, 1964; Hoydalg et al., 1982 (referred by Sparre and Venema, 1992)].

\textbf{RESULTS}

\textit{Weight-related results}

\textit{Catch composition}

The overall total catch during the research cruise was 19,280kg of which 12,278kg was by-catch and 7002kg were shrimps (marketable shrimps). Of the by-catch 10,171kg was fish by-catch. A total of 70 species (plus organisms assigned to higher taxonomic groups) were identified, with a mean of 25 identified species per haul.
The most abundant shrimp species by weight was *P. indicus* (30.9%), but in number it was the group Caridea. In the fish by-catch, *Trichiurus lepturus*, *J. dussumieri*, *O. ruber*, *Pellona dichela* and *T. vitrirostris* were among the five most abundant by weight (16.6, 7.5, 6.7, 6.3 and 4.8% of total catch respectively).

The estimated proportion of by-catch in the overall catch was 64% with 95% confidence limits from 46 to 74% of the total catch by weight. The by-catch proportion was highly variable between hauls. There was no clear indication of depth dependency on catch rates. No marked diel pattern in the shrimp catch rate related to the time at start of tow was observed.

**Gear performance when using cod-end cover**

Based on a pair-wise comparison randomisation for both the 55 (Group I) and 60mm (Group II) cod-ends, the by-catch rates were significantly greater in covered trawls (*p* = 0.03; *p* < 0.01 respectively). The higher catch rate in the cod-end with cover indicates that there is a masking effect by the cover.

A comparison between the catch rates taken in 55mm with grid and 60mm (group III) showed no difference for either by-catch rates (*p* = 0.14) or shrimp catch rates (*p* = 0.17) as well as for shrimps in groups I and II (*p* = 0.30 and *p* = 0.63 respectively).

**Catch proportion**

No significant relationship was found between the by-catch rates excluded and the overall catch rates for a haul for the 55 and 60mm cod-ends for all three groups (*p* > 0.05). The same result was observed for shrimps except in group III (*r^2* = 0.52; *p* = 0.04). These results showed that in most of the cases there was no correlation between proportion of shrimp or by-catch rates excluded and total catch rates within the ranges observed (86–113kg/h).

**Length-related results**

**Masking effect**

Significantly higher mean lengths of by-catch specimens caught in the main bag on the port-side (without cover) than those caught in the main bag on starboard side (with cover) were obtained for *O. ruber* in 55mm mesh (*p* < 0.001) and *J. dussumieri* in both 55mm and 60mm meshes (*p* < 0.001). This indicates a masking effect by the cover. *Thryssa vitrirostris* showed no difference in mean lengths between port side and starboard side (*p* > 0.05), and indicating the absence of a masking effect.

**Mean lengths retained in main cod-end and cover**

The randomisation test (Kolmogorov-Smirnov) indicated that all the three fish species had significantly greater mean lengths in the cod-end than in the cover for 55mm cod-end. For 60mm cod-ends, the lengths were also greater in the cod-end than the cover, but the differences were not significant for *O. ruber* (G II *p* = 0.07) and *T. vitrirostris* (G III *p* = 0.70). For *J. dussumieri*, all cases were significantly different. Based on randomisation
test (Kolmogorov-Smirnov), the mean lengths for all three species in the 55mm cod-end with grid were significantly higher than those in the main bag of 60mm mesh (without grid) (p<0.001). Table 2 presents the selectivity parameters using both covered cod-end and trouser trawl methods to investigate the extent to which the methods influence the selection of cod-end and a combined cod-end and grid system.

**Selectivity estimates from covered cod-end method**

Based on the covered cod-end method, the fitted selection curve showed that the probability that *O. ruber* was retained by both 55mm and 60mm meshes increased very slowly with increasing length of fish, i.e. showed a wide selection range and poor model fit. It also showed a higher variability of selection between individual hauls. For the 60mm mesh cod-end most of the samples did not fit the model (Table 2; Figure 6). The selection curve for *J. dussumieri* is not shown since the results obtained were inappropriate (Table 2). The exclusion of the samples from the analysis can arise because of poor selectivity of the meshes caused by masking effect which is influenced by the shark protection and cover. This makes the selection a more-or-less random process.

Table 2. Size selection estimates by using the covered cod-end method (CCM) and trouser trawl method (TTM). Confidence intervals (95%) for the estimated parameters are also given

<table>
<thead>
<tr>
<th>Selectivity parameters</th>
<th>Cod-end mesh size and grid (mm)</th>
<th>55 (G. I)</th>
<th>60 (G. II)</th>
<th>55 + grid</th>
<th>60 *(G. III)</th>
<th>TTM (G. III)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCM</td>
<td>TTM</td>
<td>CCM</td>
<td>TTM</td>
<td>CCM</td>
<td>TTM</td>
</tr>
<tr>
<td><strong>Otolithes ruber</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L&lt;sub&gt;25%&lt;/sub&gt;</td>
<td>8.4 ± 8.5</td>
<td>12.6 ± 3.0</td>
<td>8.2 ± 4.7</td>
<td>11.3 ± 2.5</td>
<td>11.8 ± 1.9</td>
<td>5.4 ± 25</td>
</tr>
<tr>
<td>L&lt;sub&gt;50%&lt;/sub&gt;</td>
<td>13.7 ± 5.0</td>
<td>14.9 ± 2.2</td>
<td>15.4 ± 6.0</td>
<td>12.8 ± 2.0</td>
<td>13.2 ± 1.1</td>
<td>12.1 ± 9.4</td>
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# inappropriate selection parameters; * port side (55mm mesh + grid) vs starboard side (60mm mesh).
Figure 6. Length distributions of *Otolithes ruber* (Or), *Johnius dussumieri* (Jd) and *Thryssa vitrirostris* (Tv) using trawls with 55mm and 60mm mesh sizes. The selection curve for each haul (dashed line) and mean selection curve (solid line) given by the covered cod-end method are shown.
Figure 7. Length distributions and selection curve for each haul (dashed line) and mean selection curve (solid line) of *Otolithes ruber* (Or) and *Johnius dussumieri* (Jd) using cod-ends with 55mm and 60mm mesh sizes and 55mm mesh with grid by the trouser trawl method.
Selectivity estimates from trouser trawl method

*Otolithes ruber:* The fitted selection curves had narrower selection ranges for the 55mm mesh cod-end combined with grid than for the 55mm without grid. However, the mean selection length was highest for the 55mm cod-end without grid (Table 2 and Figure 7). The $L_{50\%}$ for the 55mm cod-end was also higher than the mean selection length for the 60mm mesh cod-end.

*Johnius dussumieri:* The fitted selection curves (Figure 7) showed that the steepness of the curves for 55mm cod-end with and without grid is about the same. The mean selection length is higher in 55mm cod-end with grid (Table 2).

Since there was no masking effect for *Thryssa vitrirostris* there was no need of using trouser trawl method.

DISCUSSION

**By-catch ratio**

The overall shrimp to by-catch ratio found in this survey, 1:2.3, is towards the lower end of the range estimated previously for the commercial shrimp fishery in Mozambican waters, i.e. 1:3 (Pelgrüm and Sulemane, 1982 [cited in Sparre and Venema, 1992]), 1:3.3 for the years 1983–1984 (Gislason, 1985), 1:5 for the year 1993 (Anon, 1994b) and 1:4.3 for the years 1986–1990 (Pacule and Baltazar, 1995). Kennelly et al. (1998) concluded that the occurrence and quantity of different species in by-catches depend on the year, season and location in question. In this analysis the escaped specimens were considered, which is not possible on commercial rigging and there was relatively high shrimp catch rates in this cruise. Moreover, the composition of by-catch may change as a consequence of river runoff according to tolerance for low salinity of some species. The exploitation patterns seem to play an important role on the sizes and species captured (some previous estimates were based on data from the commercial fleet using lower mesh size, 45mm up to 1994) (Silva et al., 1995).

**Degree of association between shrimp or by-catch loss and catch size**

One way to obtain an index of the efficiency of the selection device (cod-end or grid system) is to evaluate the relationship between retention and the size of the catches. The results showed no saturation of the cod-ends, in that the proportion retained was not correlated with catch size within the ranges observed (236–2320kg and 86–1113kg/h). However, an exception was found in 60mm mesh (G. III) that showed a positive relationship between shrimp catch rate excluded and total catch rate ($r^2 = 0.52, p = 0.04$). This could be due to small samples available.

**Masking effect**

The weight and length results from these experiments did indicate some masking effect of the cover when applied to 55mm and 60mm cod-ends. In this experiment, the cod-ends were surrounded by a shark protection net (an open cylinder) attached just behind the retriever strap and ending 70cm aft of the cod-end knot. The small-meshed cover was
fitted inside this protection net. The selection process takes place in the cod-end, mainly at the escape zone (just in front where the catches accumulate). This net in combination with the cover can cause variation in the shape of the bag to such an extent that it can prevent fish from escaping through the meshes. Some additional factors that also could contribute to the existence of masking effect include: circumference of shark protection net used around the cod-end, double layer net and mesh size used (Isaksen et al., 1995). These factors may have influenced some individuals, preventing them from escaping towards the cover, and thus, remaining in the cod-end and contribute to reducing mean individual size. Consequently, selectivity parameters would be underestimated by using the covered cod-end method (Table 7). It has been recommended to increase the circumference of the shark protection net, increase mesh size and use single layer net to improve the mesh selectivity of the cod-ends (Isaksen et al., 1995).

Conversely, the shark protection net may not affect the selectivity of the grid. This is because the grid is placed in front of the cod-end (extension piece), where the selection takes place. However, the use of a shark protection net is absolutely necessary in order to keep the sharks from tearing apart the bag. Thus, the grid is expected to perform better than cod-end mesh selection since the selection of this device is not affected by the shark protection net.

A similar masking effect was found by Isaksen et al. (1995) when analysing data for shrimp selectivity. Mahika (1992), without reference to the mesh size, and Baio (1996) using 43mm mesh size, did not find masking effect in the Tanzanian and Sierra Leonean waters respectively. This is probably because of associated differences in body shape of the species analysed, reflected in different behaviour and different trawl rigging (shark protection net was not used). No masking effect was obtained for T. vitrirostris in the present study. It may be due to its slim body shape and different visual response (Wardle, 1986), and the flexibility of the meshes made of polyamide with wide opening range. These aspects may contribute to allowing the species to better escape through the meshes.

Size selection estimates
Generally, the smaller the mesh, the smaller the fish that can be retained in the cod-end. The mean lengths obtained when the grid was used in combination with 55mm cod-end were significantly higher than those in the 60mm mesh for all three fish species studied (p<0.001). The expected result would be higher mean lengths in larger mesh (60mm). This did not happen probably due to the masking effect mentioned in previous sections. An indication of efficiency of the fishing gear selectivity based on size is the selection range (Anon, 1996c). The fixed spacing between bars grid usually have a sharper selection than cod-end meshes which usually are composed of meshes of variable sizes.

The covered cod-end method gave biased selection parameters and low precision of the estimates probably due to a masking effect. The trouser trawl method gave improved estimates of selection parameters and the more precise estimates. However, several hauls were excluded from the analysis because the data did not fit the model. The exclusion
of samples from the analysis may have to do with poor selectivity of the meshes caused by the presence of the shark protection net and cover which makes the selection become more or less a random process, i.e. sub-samples were too small to adequately reflect size composition in catches. It seems that better results could be obtained with increased number of samples. The more precise estimates were obtained for *O. ruber* in 55mm cod-end without grid and *J. dussumieri* in 55mm cod-end with a grid.

The results suggest that the top-grid in combination with 55mm meshed cod-end had better selection properties to the species compared to both the 55mm without grid and the 60mm meshed cod-end.

No comparisons were made with other similar studies because of differences in cod-end mesh size, grid bar spacing and species examined as mentioned before in this section. However, the two durations reported by Mahika (1992) (2.75 hrs) and Baio (1996) (2–2.5 hrs with towing of speed 3–3.5 knots), are approximately equal to those used in this experiment (2–3 hrs and 3.2 knots). Thus, the selectivity parameters regarding the three species using a 14.0mm space bar should be regarded as first estimate.

**Cod-end and grid sorting capacity**

In shrimp fisheries in tropical areas, most fish by-catches comprise small specimens of about the same size as the target shrimp species. Therefore, it is difficult to sort out (exclude) the fish by-catch based on size selectivity by controlling cod-end mesh size (Brewer et al., 1998). The selectivity of the top-grid system is based on behaviour differences and physical characteristics of the grid, therefore intending to exclude more small specimens. Thus, the selection efficiency of a gear in this case is determined by lower retention of small fish. This principle was fulfilled by the 55mm mesh cod-end with top-grid, which excluded small fish while maintaining medium and bigger ones in the cod-end, which is in agreement with Isaksen et al. (1995). Escaped specimens (shrimp or fish) with lengths below their mature length can then grow bigger and be fished later. This can lead to reduction of fishing mortality of small sizes of fish (to some extent) and higher yield per recruit (i.e., more value). It is possible to regulate the grid bar distance as it is done for cod-ends to suit the management requirements. Thus, selective devices such as grids may help reduce by-catch. However, the reduction of by-catch may, to some extent contribute to an increase of biomass of shrimp predators, leading to increased mortality by predation on shrimps (Bianchi, 1992). Consequently, the biomass of shrimps may decline, on one hand. On the other hand, removing huge quantities of small shrimp and fish by-catch, may lead to changes in fish dominance structure or even depletion of some stocks (Jin, 1996).

Once the fishing industry faces time and space limitation to deal with by-catch, and the use of devices (grid) does not reduce the gear efficiency (Hall, 1995), the reduction of non-target animals (especially small-sized specimens) using grid or other gear configurations, e.g. square meshes (Broadhurst and Kennelly, 1994) would lead to smaller catches to be sorted on board, more clean catches of target species and consequently,
longer tow times and lower fuel costs per unit of target species caught (Brewer et al., 1996).

CONCLUSIONS

This study analysed the selectivity for important by-catch species in the Mozambican shallow-water shrimp fishery. The analyses revealed that the rigging of the trawl with a shark protection net over the cod-end, most probably reduced the efficiency of cod-end mesh selection.

The cod-end mesh size selectivity parameters were not well estimated and the results were partly inconsistent. In addition to the masking by both cover and shark protection net, sample sizes were generally too low (probably due to poor selectivity of the meshes) to adequately reconstruct the length frequency distribution of the catches. Therefore, it is important to guarantee the absence of masking effect in order to obtain a good selectivity of the meshes.

The results from the experiments with a rigid grid showed that the grid in combination with a 55mm mesh cod-end gave higher mean length of the catches than the 60mm mesh cod-end. The grid also showed sharper selection curves. Moreover, the shark protection net does not affect the efficiency of grid selection.

Previous analysis of the shrimp data from the present selectivity experiment has shown that a 60mm cod-end mesh size leads to an unacceptably large shrimp loss (up to 30%). The present experiment has shown that cod-end mesh exclusion for by-catch species is low for both 55 and 60mm mesh cod-ends due to the use of shark protection nets. However, fishing without a shark protection net in the Mozambican shrimp fishery is not practical, since sharks would severely damage the cod-end during haul back with a subsequent loss of shrimp catch.

To reduce the high discard of by-catch (including undersized target species) it is recommended to carry out further selectivity experiments in the Mozambican shallow-water shrimp fishery. Experiments should include more comprehensive trials with the rigid grid. The role of the shark protection net should also be further explored, and construction guidelines should be made in order to reduce its masking effect during commercial fishing.

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Economic impacts of marine protected areas: A case study of the Mombasa Marine Park

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ABSTRACT

The conservation of the marine environment is an integral part of the broader initiatives of environmental conservation in Kenya. A major motivation for the delineation of marine protected areas (MPAs) in Kenya has been the promotion of tourism and also the need to conserve marine biodiversity for posterity. However, the conservation of marine resources in Kenya has led to certain resource-use conflicts between national conservation agencies such as the Kenya Wildlife Service and local fishing communities. The study reported in this paper sought to examine the economic implications of the Mombasa Marine Park on a local fishing community, and thus provide an insight into the factors that lead to such conflicts.

In the study, catch-related variables pertaining to the marine protected area were found to be significant. At the same time, attitudes of local fishermen towards the establishment of the Park were found to be extremely negative. The reasons for this included park establishment procedures as well as the lack of alternative sources of income for the communities displaced from the area now managed as a marine park. This paper recommends that in establishing an MPA in a developing and demographically dynamic country like Kenya, conservation authorities must be well aware of and integrate existing traditional systems of resource use into modern management practice. This may be achieved through a multidisciplinary approach to the varied issues related to the establishment and management of MPAs. This approach should build the capacity for active resolution of any resource use conflicts that may arise.

INTRODUCTION

For centuries the oceans and seas have been a major resource base for humankind, especially as a source of food and transport opportunities. Together with the fact that coastal zones are among the regions of highest biological productivity on earth, high population densities have emerged in these zones—60% of humanity lived in coastal
zones in 1992 compared with 50% in 1970 (Tolba and Elkholy, 1992). Previously, the resources of the marine ecosystems of the world have been regarded as openly accessible, with users’ needs having a greater priority than the health of the environment.

In the 18th and 19th centuries, little attention was given to conservation of marine living resources as the sea was principally used for navigation, fisheries and periodically for warfare. Any claims on the sea that were made with intent at conservation were clearly an exception to the predominantly commercial outlook of the sea that prevailed at the time. The first attempt at placing some manner of control over the exploitation of marine resources became evident with the formulation of the three-mile limit of sea jurisdiction established by the British Parliament, with the passing of the Territorial Waters Act of 1878 and the Sea Fisheries Act of 1883. Though the declaration of this limit became accepted practice over the 19th century, it contributed to few conservation measures owing to the fact that the narrowness of the three-mile sea dimension made protection of marine living resources such as fur seals difficult to realise (Wilder, 1998).

The second half of the 20th century has seen increased realisation that it is impossible for humankind and the majority of the earth’s life forms to thrive without healthy seas. Environmental degradation of the seas was initially highlighted in the 1950s and 1960s (Kelleher and Kenchington, 1991), leading to a gradual shift away from the perception that marine resources were ‘infinite’. There was a growing realisation that apart from marine pollution, over-exploitation of marine resources was an equally that damaging process that sets into motion irreversible and sometimes synergistic destructive processes such as population decline, species extinction, impoverishment of genetic banks as well as alterations of trophic relationships.

In 1975 the IUCN International Conference on Marine Parks and Protected Areas held in Tokyo passed resolutions that paved the way for the establishment of marine protected areas (MPAs) as the popular mode of implementing marine protection (Kenchington, 1990). In Kenya, as in other parts of the world, marine parks are established for the main purposes of protecting biodiversity, as well as the promotion of tourism—traditionally one of the top three foreign exchange earners for the Kenyan economy. Over time, other roles of marine parks in the country should necessarily evolve to include education of the public regarding the importance of conserving marine biodiversity as well as the provision of research media for marine scientists (Chebures, 1989). In Kenya, marine fisheries forms a major component in employment and revenue generation for numerous coastal dwellers. Many of these are indigenous coastal peoples whose basic economic and social well being is linked to the exploitation and use of marine resources.

Many developing countries are increasingly experiencing socioeconomic stresses emanating from the discrepancy between the available resources and rapid population increase. The continued rise in populations is a major factor in the emergence of resource-use conflicts and environmental degradation. It has therefore become imperative for countries to continually seek avenues by which environmental protection
may be implemented and managed in a sustainable manner. The potential of ‘ecotourism’—a practice that should necessarily contain ethics for environmentally responsible behaviour that at the same time strengthens the conservation ethic (Westerink, 1996)—as an important source of foreign exchange has been recognised by many developing countries, including Kenya. In this regard, the government of Kenya recognises the importance of protecting outstanding natural ecosystems, such as those found within the marine environment, for future generations. However, government policies in the marine realm, both for conservation and the promotion of tourism, have resulted in conflict and resentment from affected users of the areas placed under protection, mostly local fishing communities, which have been relegated to less lucrative fishing grounds during the enforcement of park rules and regulations. A conflict has thus unfolded between the need for natural resource conservation and that of managing the conserved resources in a way that does not impact negatively on the economic welfare of indigenous resource users.

Few studies in Kenya, and indeed in the East African region, have addressed themselves to an economic analysis of the impacts associated with marine conservation. In recognition of this deficiency, a study was conducted to examine the economic impact of marine conservation on a local fishing community at the Jomo Kenyatta Beach which is adjacent to the Mombasa Marine National Park.

Objectives of the study
The objectives of the present study were specifically to:

- assess the effect of a change in access to fishing rights on the income of local fishermen (a change represented by the changing levels of catch per fisherman and the number of fishermen);
- establish if there exists a direct relationship between tourism to the Marine Park and income of fishermen displaced from the park;
- evaluate the perceptions of the fishermen towards the existence of the Mombasa Marine National Park; and
- provide some recommendations and policy guidelines based on the findings of the above objectives.

STUDY AREA
Kenya was the first African country to establish marine protected areas, the Malindi/Watamu Parks and Reserves established in 1968 (Chebures, 1989). The original motivation for their establishment was mainly the need to earn foreign exchange through tourism. Other parks and reserves have subsequently been set up in reaction to perceived problems such as the over-exploitation and destruction of marine habitats.

The study area for this paper was the Mombasa Marine Park. Though gazetted in 1986, it was not until towards the mid-1990s that park and reserve rules and regulations began to be strictly enforced. The objectives for establishing the park included preservation
of the marine habitat, revenue generation through tourism, education and scientific research. Both the park and reserve are government property. Located on the north coast of Mombasa town, the Park extends from the Nyali area to Mtwapa creek and has an area of 10km². This area falls within the broader Mombasa Marine Reserve, which covers 200km². The Park and Reserve areas include extensive coral reefs, a coral garden, a channel, some cliffs and a number of beaches which offer recreation to locals and tourists alike. The Park accommodates the main recreational site for Mombasa town residents at the public beach.

Visitor statistics show a drastic decline since 1997, attributable to factors such as poor infrastructure and periodic incidents of insecurity within the coastal region. At the same time a number of internal difficulties hamper the smooth management of the Park, such as lack of funds and insufficient well-trained staff.

The protection of marine resources is the responsibility of a national conservation body, the Kenya Wildlife Service (KWS). When the KWS implemented rules for the Mombasa Marine Park, part of the result was the immediate enclosure of an area previously regarded by fishermen as containing a ‘common resource’. Enclosure and the associated prohibitions to entry and exploitation of the resource base have both been responsible for upsetting the previous pattern of use and exploitation and instead introduced a new system of resource management that is neither well understood nor accepted by traditional users. The local user community have felt deeply antagonised by the shift in the decision making power, together with the view that the new management system reflects only the interests of the conservation authority and not those of indigenous resource users (The Ecologist, 1993).

METHODS

Both quantitative and qualitative methods of inquiry were used. The quantitative aspect comprised analysis of secondary data on revenues from fish catches landed at the area adjacent to the marine park/reserve, the number of fishermen fishing in and around the marine reserve, the number of tourists visiting the Mombasa marine park as well as the catch per unit of effort data. The data were a monthly time series set beginning January 1991 through April 1998. Qualitative information was acquired with the help of a structured questionnaire that was administered in Kiswahili language to 30 fishermen from three fish landing sites. The aim of the qualitative analysis was to acquire an insight into the perceptions and attitudes of fishermen regarding the Park, its resources and the manner in which it was set up.

Statistical analysis was then carried out on quantitative data pertaining to variables chosen in the study to be explanatory or independent. The dependent variable is the revenue while the independent variables are catch per fisher/per unit effort (CPUE), tourists numbers in the park and number of fishermen. Analysing the statistical significance of each of the variables facilitates the drawing of inferences regarding the possible effect that a negative impact on some of the variables may have on the economic status of fishermen.
Quantitative data on the variables are analysed using a regression analysis that utilises the ordinary least squares (OLS) estimation technique. Since OLS assumes that variables are stationary, some unit root tests are first carried out on the data to ensure that variables indeed exhibit stationarity. The following is the general form of the equation estimated for the quantitative data in the study:

\[ W_t = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 X_{2t} + \alpha_3 X_{3t} + \alpha_4 D_t + E_t \]

where:
- \( \alpha_0 \) = Constant term
- \( W_t \) = Revenue from fish sales
- \( X_{1t} \) = Number of fishermen
- \( X_{2t} \) = Number of tourists
- \( X_{3t} \) = Catch per fisher/per unit effort
- \( D_t \) = time dummy capturing the period of December 1995
- \( E_t \) = Error term.

**RESULTS**

After applying the unit root tests, the dependent variable (on the left side of equation 1) becomes *change in revenue* (as opposed to revenue) while lagged values of this change in revenue become additional dependent variables (dependent/explanatory variables are located on the right side of the equation). Lagged values of the number of fishermen and the catch per unit effort are also added to the set of explanatory variables. These additions are incorporated into the above general equation to give the following final equation:

\[ D_{rev} = f \left( \text{Constant, } D W_t \cdot -1, D W_t \cdot -2, D W_t \cdot -3, D W_t \cdot -4, D W_t \cdot -5, X_{1t}, X_{1t} \cdot -2, X_{2t}, X_{3t} \cdot -1, X_{3t} \cdot -2, X_{3t} \cdot -5, D9512 \right) \]

Table 1 presents the results obtained after a regression of the new equation/model is carried out.

The last column, titled ‘t-Prob’, gives an indication of the level of statistical significance for each of the corresponding variables in the first column. Accordingly the variables with the highest degree of statistical significance (1%) are:
- The first four lags of changes in revenue
- The number of fishermen
- The catch per unit effort
- The dummy variable.

The number of tourists to the marine park has less significance than the other variables listed above, with significance standing at 5%. The R² value indicates that 89% of the dependent variable (i.e. change in revenue) is accounted for or explained by the independent variables.
Fishing revenues

The results suggest that past trends in revenues from fish catches are important in explaining current changes in revenue. However, the coefficients of the lagged changes in revenue bring to light an important observation that past increases in revenue do not necessarily always lead to increases in revenues in the following period. This is explained by the fact that no additional capital investment is done by fishermen. Together with a continued upward trend in inflationary pressures, the capital base, e.g. fishing gear becomes worse over time ultimately reflecting itself in reduced revenues. With the enhancement of park rules and regulations and the imposition of gear restrictions in the marine reserve, the situation is only made worse. Fishermen incomes are thus negatively affected by a change in access to certain fishing areas. Perhaps the situation would be different if the fish spillover from the marine park into the marine reserve were substantial.

Fishing is still an important activity to the now reduced number of fishermen in and around the Mombasa marine reserve, as indicated by the significance of number of fishermen and the catch per unit effort. The dummy variable captures an erratic increase in fish catch data, for example owing to the seasonal migration of fish species such as sardines.

Effects of tourism

Partly from the statistical analysis and from discussions with fishermen, the study found that there is no direct relationship between the number of tourists visiting the Marine Park and fish-derived income for fishermen. This is because fish catches from local fishermen do not find their way into the tourist centres located adjacent to the park. This is the area from which the majority of the tourists to the park come from. The reason why these places are not a market for the fishermen’s catch is because the quantity and quality does

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Table 1. Regression results of the new equation/model

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<tr>
<td>X_{t-2}</td>
<td>-522.34</td>
<td>156.17</td>
<td>-3.345</td>
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<tr>
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<td>90.315</td>
<td>-3.484</td>
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</tr>
<tr>
<td>D9512</td>
<td>2.0657e+005</td>
<td>30402</td>
<td>6.794</td>
<td>0.000</td>
</tr>
</tbody>
</table>

R² = 0.892386.
not meet the required standards. Any relationship that exists is indirect arising from the fact that tourists to the park (and therefore the hotels etc. in the area) lead to a certain increase in the area’s ‘local’ money supply, which the local people tap mostly in the form of employment in tourist centres. The money earned may then be responsible for increasing the purchasing power of local people, and this enables them to purchase more goods, including fish caught by the local fishermen operating within and around the Marine Reserve.

Fishermen’s perceptions
Detailed interviews with fishermen found that, on the whole, their attitude towards the Park’s existence and management were negative. These attitudes developed as a result of the following factors:

- **Park inception.** Fishermen complained that not enough consultations were carried out between them and KWS. Accordingly, KWS was accused of surprising the fishermen with the demarcation of park and reserve boundaries, using force and intimidation to do so.

- **Compensation.** Not enough compensation or viable alternatives were presented to the fishermen after they were prohibited from fishing in the area taken up by the park. Gear restrictions were enforced in the adjacent marine reserve. According to them, this area contains the most lucrative fishing grounds. At the same time fishing gear is costly for the fishermen, the majority of whom have very limited financial resources. It has thus been impossible for them to replace worn out and inefficient gear with more sophisticated equipment that would enable coverage of greater sea distances to look for better fish catches.

- **Education and vocational status.** Most fishermen were discovered to be of significantly low educational and vocational status and still living within an extended family setup. This inevitably implies that fishermen have minimal or no opportunities for alternative employment.

**DISCUSSION**

It is now acknowledged by many that environmental conservation is an issue that can no longer be downplayed. At the same time, conservationists and governments have realised that economics and the protection of the environment can no longer be taken to be mutually exclusive aspects. To this end, if economics and conservation are to be non-mutually exclusive, there is need to answer the question of how the economic costs of conservation are to be met and by whom. Conservation authorities should conduct comprehensive pre-establishment studies geared towards assessing the value of the marine resources to be conserved. This is important because sites identified as prime areas for conservation are normally the most economically viable ones to local fishing communities.

Also vital are post-establishment studies that utilise techniques such as cash flow and risk analyses. These analyses help to create an understanding of the magnitude
and extent of the conservation costs that local communities have to bear such that in the medium to long term the possibilities of sharing conservation costs should be well investigated and eventually made a reality.

Since part of the conflict within a marine protected area revolves around the issue of property rights, it is essential for conservation authorities to be aware that certain traditional systems of resource use have existed in most areas for centuries. It is therefore prudent for these authorities to establish the least contentious ways of limiting the traditional freedoms pertaining to indigenous resource users, thereby helping to protect the property rights systems that may exist in such local communities. This can be achieved by the use of well conducted interdisciplinary studies that aim at gaining in-depth knowledge and also an all-round perspective of local communities around protected areas.

Accepting that negative reactions from the community of users are anticipated in establishing MPAs, more so in poorer countries, the challenge that exists for implementers of conservation is that of re-channelling that negativity into a more positive response for the project. From the planning stages, local people should be frequently consulted concerning the selection of the conservation site, the formulation of rules to govern the area as well as in the attempt to achieve a consensus regarding the rate at which the conservation project should be implemented. This latter aspect is vital in enabling affected communities like those of fishermen to acquire alternative sources of income such as may be found in tourism. Though acceptance may be difficult to achieve in the short run, it might be achieved by empowering local communities in ways that make them feel that they are partners in the conservation project. This in turn helps to sow the seeds for longer-term understanding and even appreciation for the project.

It should be the aim of the national government to assist (directly or indirectly) in providing an enabling environment that facilitates the strengthening of financial, managerial, technical and human resource capacities for conservation initiatives. This enables the conservation authorities to adequately deal with a myriad of issues pertaining to communities excluded from areas designated for conservation. The above capacities should necessarily help to create multi-institutional collaboration in order to avoid the duplication of conservation activities, increase efficiency and thereby avoid wastage of resources. In this way conservation institutions become better focused on project goals and activities.

An overlooked aspect of conservation in developing countries regards the collection and proper documentation of data over time. Lack of or insufficient data hinders progress in research. Data collection and management for a broad spectrum of marine resources, their uses and the various users should be an important goal for organisations involved in conservation work. However, data collection and management is a necessary but not sufficient condition for successful environmental conservation. Ultimately, it is the implementation and maintenance of sustainable coastal development programmes that will prove decisive in the achievement of successful marine conservation.
CONCLUSION

The delicate balance of people and resources within marine areas has frequently not received the attention it deserves. Indeed governments and local communities have been slow to grasp those crucial concepts that are needed to maintain the marine environment’s monumental link in the ecological chain of life. Without proper planning and implementation, among the first groups of people to suffer economic losses as a result of marine conservation are fishermen. They suffer economic adversity through declines in incomes/revenues as well as through lost employment opportunities when they are excluded from a protected sea area. Declines in earnings are as a result of lower levels of individual and therefore total fish catches. In Kenya this has necessarily led to conflict between local fishermen and the national conservation organisation, the Kenya Wildlife Service.

The negative impacts of conservation, especially on fishermen, are mostly as a result of the lack of alternative economic opportunities for them. Factors negatively influencing fish catch levels such as gear restrictions contribute to a sizeable decline in fish catches from the adjacent marine reserve where a few fishermen are allowed to operate. Further, local fishermen negatively affected by the establishment of the marine park do not have enough technological and financial capacities to help them venture into more lucrative fishing grounds which are further out at sea. The only alternative left to them is to look for new horizontal fishing grounds which in many cases will have other fishermen operating in them. This invasion breeds conflict as initially those they find in the new fishing grounds reject the migrant fishermen. With time, however, the new fishermen get integrated into the group with the result that the average catch per fisherman drops.

It is imperative that conservation attempts be selective in the adoption and implementation of various conservation policies. At the same time, different marine ecological zones within a country need to be carefully studied as to their potential economic as well as social impacts if they do acquire protection status depending on the local issues involved. It is the local issues that ultimately determine the alternative opportunities that local people may have when protection is fully implemented. Additionally, conflict between users and conservation agencies, as in the case of the Mombasa Marine Park, is mostly as a result of information asymmetry, whereby local people are not clearly informed from the start about what conservation fully entails.

Conservation of the marine environment has therefore to enter a new management era in which good planning is not enough but has to be accompanied by legitimate implementation practices which have full knowledge of the conservation site and its dependants. The dependants in turn have a right to know and also an obligation to learn about the fundamental issues pertaining to conservation of the marine environment. If local resource users understand these issues, then conservation-related conflicts could be avoided if not greatly minimised so long as conservation organisations fully recognise the needs, endowments and also the rights of local communities dependent on the resources being conserved.
REFERENCES


Coastal resources of Bagamoyo District, Tanzania

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ABSTRACT

The major findings and lessons learned from a three year study (from 1996–1999) undertaken by an interdisciplinary team on the coastal resources of Bagamoyo District, Tanzania are presented. The study looked at crustacean resources, finfish resource, coral reefs, mangroves, algae, seagrasses, socioeconomic potential of the area, and indigenous knowledge and practices as related to fisheries and various habitats. It has been shown that the coral reefs are the main fishing grounds of artisanal fishermen and there are about 1100 artisanal fishermen using 120 traditional vessels. There are 10 trawlers operating for prawns and these compete and conflict with artisanal fishermen. Twenty different types of sea cucumbers (beche-de-mer) are harvested but only seven among these are the most commonly harvested. Both sea cucumbers and molluscs, especially gastropods, are harvested by hand-picking from the intertidal reef flats or snorkel diving over sand and seagrass beds. Women are involved in processing and marketing of fish and collect shellfish in intertidal flats where they are reached by foot. Women’s catch is mainly used in the family and only a small fraction is sold for cash. All fishermen interviewed agreed that the stocks of prawns, fish, crabs, sea cucumbers and molluscs have declined through over-fishing and the removal of undersized individuals. The mangroves provide habitats for fish and other animals and are a source of fuelwood, charcoal, fishing stakes, building materials and traditional medicines. Solar salt production and tourism are important activities in Bagamoyo. Although the majority of the people depend on the coastal and marine resources, the harvesting rates of most resources are not known. There is a lack of awareness among users of the linkages of the various coastal ecosystems but they have vast traditional knowledge on some of the resources.

The experiences from Bagamoyo suggest that marine scientists and
resource managers can gain new insights through dialogue and partnership with coastal inhabitants. We believe that through discussions and collaboration with coastal dwellers in the research process, new questions can be identified and the scientific analysis can be improved through new insights.

INTRODUCTION

Tanzania’s coastal marine ecosystems include mangroves, seagrass beds, coral reefs, lagoons, sand flats, mud flats, coastal forests and grasslands, beaches and sand dunes (Semesi, 1992; Semesi and Howell, 1992; Semesi and Ngoile, 1993; Linden and Lundin, 1996). The quest for economic growth is increasing pressure on all coastal resources. Examples of destructive resource utilisation include: clear felling of mangroves for poles and salt production, building of hotels on the shoreline and sand extraction on the beaches, estuaries and river beds. All these activities result in resource use conflicts and beach erosion, which affect the very base of the coastal economy.

According to many reports (for example, Semesi and Ngoile, 1993; Linden and Lundin, 1996; Semesi et al., 1998) the root causes that contribute to the mismanagement of coastal and marine resources besides population growth in Tanzania are:

Inadequate awareness
There is inadequate awareness on marine ecological systems, the state of the environment and the resources, the socioeconomic structure in the area and resource-use conflicts, as well as of policies, legal and institutional frameworks.

Inadequate knowledge and skills
The knowledge base is weak and cannot cater for sound management.

Resource use conflict
There are no mechanisms in place to resolve resource use conflicts. The competition for use is much more for common-access marine resources such as fisheries and mangroves.

Weak institutional arrangements
Lack of clear policy as well as inadequate, overlapping legislation, and insufficient management capacity is another cause of mismanagement. Further, the division of responsibility between institutions is blurred and there are difficulties in exercising law enforcement.

In response to some of the issues raised above, the government (at the national level) is committed to establishing the foundation for effective coastal governance which is an essential pre-condition to the improvement of the quality of the coastal environment, sustainable coastal development and improvement of the quality of life of coastal residents. To this end, the government has formulated an integrated coastal zone management policy that is applicable to coastal problems at both the national and local levels (TCMP, 2000).
The present study was carried out in order to raise awareness and improve the knowledge of the distribution, seasonality, and the factors controlling the population dynamics of selected resources in Bagamoyo. This paper provides a summary of the results of a three-year study (1997–1999) and the lessons or experiences gained while working in the interdisciplinary team.

LOCATION OF STUDY SITE

Figure 1 shows the study area. Intensive sampling was carried out from the Ruvu River mangroves to Mbegani Fisheries Development Centre. The coral reefs covered were those at Mwambakuni, Mwambapwani and Mwambamjini.

MANGROVES

Distribution

The mangroves of Bagamoyo District form a more-or-less continuous band along the 100-km coastline from Saadani to near Kitame salt works, and then from Ruvu River to Mpiji River (Figure 1). They cover an area of 5635ha (Semesi, 1991). The main mangrove stands are found along: (a) Wami River, 862ha, (b) Utondwe creek, 834ha, (c) Ruvu River, 2123ha, and (d) south of Bagamoyo to Mpiji River, 809ha. By 1989, clear-cut areas and salt pans covered 1639ha (Semesi, 1991) and water in the creeks covered 812ha. Environmentally stressed mangroves—those not more than 5m high covered 1154ha and about 2653ha had a stand height of over 10m.

Vegetation

Of the eight mangrove tree species, *Rhizophora mucronata* (‘mkoko’) and *Avicennia marina* (‘mchu’) together make up over 70% of the area covered. Others present are *Ceriops tagal* (‘mkandaa’), *Bruguiera gymnorrhiza* (‘mshinzi’), *Sonneratia alba* (‘mpira’), *Heritiera littoralis* (‘mkungu’ or ‘msikundazi’), *Xylocarpus granatum* (‘mkomafi’) and *Lumnitzera racemosa* (‘mkandaa dume’). *Rhizophora mucronata* is dominant on muddy soils, the most favourable substrate for this species, and often forms pure stands. Numerous stilt roots make the *Rhizophora* zone almost impenetrable. Trees may attain heights of up to 12m but many were about 6m tall. *Bruguiera gymnorrhiza* covered only a small area in the mangroves of Ruvu, and was often found mixed with *R. mucronata* and *Ceriops tagal*. *Sonneratia alba* forms pure stands on the seaward side of the coast, where the substrate is usually soft, fine silt and mud. *Sonneratia alba* is colonising newly formed areas on the seaward side. Walking across this zone is extremely difficult because of the large peg roots and the softness of the substrate. *Heritiera littoralis* is a riverine mangrove species that grows only in habitats with low salinity and thus is restricted to areas away from the sea. Such sites are usually only flooded by spring high tides, and usually the substrate is firmer compared to those on which other mangrove species are found.
Avicennia marina grows on compacted substrate, sand flats and/or on newly deposited sediments. As a result, it is the most widely distributed species and is found on the landward margin. It forms pure stands and can also appear mixed with others, particularly Ceriops tagal and Xylocarpus granatum. Where sedimentation takes place up-river, dense Avicennia marina colonises. Many clear-felled areas in Ruvu were also being colonised by A. marina as long as the tidal water reached the site. However, natural regeneration in the Xylocarpus and Heritiera zone is very poor especially in areas that are heavily cut. In mature closed forests of Rhizophora and Avicennia there was no undergrowth. Xylocarpus granatum was most often found mixed with Avicennia, and it was found growing on raised portions where flooding takes place only for a few days a month and where there is fresh water influence. Ceriops tagal was largely found on the landward side of the Rhizophora zone. It became dominant more frequently in areas where mud is thin and on relatively higher ground than the Rhizophora zone.

Zonation of trees was similar to that reported in the region (Walter and Steiner, 1936; Semesi, 1986). The zonation pattern of trees in mangroves results from differences in the rooting and growth of seedlings (McCusker, 1977), the frequency of inundation by tidal water (Walter and Steiner, 1936; Semesi, 1986), soil and water salinity (Macnae, 1968), drainage and soil moisture (Grant, 1938), and geographic conditions (Banyikwa and Semesi, 1986). Due to the differences among these factors, species zonation varies from place to place. Sonneratia and Avicennia, both of which have peg roots, seem to be good pioneer species in newly formed mud. Avicennia colonise mainly along the river and on the landward side but Sonneratia occurred towards the sea. This indicates that S. alba does not withstand large salinity fluctuations as observed at Kunduchi by McCusker (1971).

Other plants seen in the mangroves were Deris trifoliata (used for fish poisoning and rope making), Acrostichum aureum (a fern), Pemphis acidula and two common lichens on dead branches of mangrove, namely Ramalina verulosa and Ramalina fecunda. Algal mats were found on sediments and attached on mangrove roots, e.g. Bostrichia sp., Centrocerus sp., Hypnea musciformis, etc. In some parts in the Sonneratia zone, macrophytic algae such as Acanthophora spicifera, Gracilaria salicornia, Hypnea sp. and seagrass Halodule sp. were found.

Uses

Village communities often look for a few direct benefits from mangroves mainly (1) firewood for home consumption or for smallscale marketing, (2) wood for charcoal making, (3) poles for housing, and (4) prawns, fish and shellfish. Mangroves are also used for boat building, fishing gear and medicine. Wood from Sonneratia alba is used for boat making and the poles of Rhizophora mucronata, Ceriops tagal and Bruguiera gymnorrhiza are used for house building. The fruits of Xylocarpus granatum are used to cure stomach problems. Compared to 1989 (Semesi, 1991; von Mitzlaf, 1989) it was found that mangrove cutting for firewood and charcoal production was much higher in 1997 and contributed significantly to the destruction of mangroves. Men, women and
children were observed carrying head-loads of wood daily and yet most had no licence to cut trees. Some fuelwood is transported from the mangrove areas by boat and lorries. Many mangrove cutters informed us that cutting mangroves is their main source of income. A head-load of mangrove fuel-wood was being sold at Bagamoyo town for up to TSh. 1200 (US$ 1.50).

Most mangrove fuelwood from Ruvu was for sale and *Xylocarpus granatum* is the preferred species because its wood burns well and splits easily. Charcoal is made from all species but charcoal making is done in areas where tidal water does not reach frequently. Thus *Sonneratia alba* that colonises seaward areas is not yet threatened by this activity. However, large trees of *Avicennia* which were not used in the past are now being cut for charcoal. Both charcoal and fuelwood are sold in Bagamoyo and Zanzibar.

The most destructive activities on mangroves of Bagamoyo are the clearing for salt-pans and clear cutting for charcoal production. Although in Tanzania there is a management plan for the mangrove forests (Semesi, 1991, 1992, 1998), this is not effectively implemented in Bagamoyo. Only three foresters are allocated to patrol all the mangroves in the District. In addition to patrolling they are required to plant mangroves in degraded areas although they have never received training on this. The revenue collection from mangrove wood is also small because most of the cutting is carried out illegally and there is no proper record-keeping in the district.

**Fauna**

Associated with mangrove forests and estuaries are a large variety of aquatic organisms, some of which are commercially valuable species, e.g. prawns (*Penaeus monodon, P. indicus*), crabs (*Scylla serrata*), milk fish (*Chanos chanos*) and sea catfish (*Arius* spp.). Other organisms such as sesarmid crabs (*Sesarma* spp.) and fiddler crabs (*Uca* spp.) (huge numbers were observed, especially in soggy sediments), gastropods, e.g. *Cerithidea decollata, Terebralia palustris* and *Littoraria* sp. are all common in the mangroves. Women and children collect shellfish species for food in mudflats/sand flats and in mangrove areas during spring tides.

*Terebralia palustris* tends to concentrate in substrates with high amounts of decomposing leaf litter. Crab concentration varies in the forest depending on the level of moisture, detritus and shade. At low tide crabs tend to concentrate in soggy areas and under shade especially those species which occupy the upper intertidal areas such as *Sesarma* spp. In the lower intertidal areas the mangrove stems and roots carry a higher biomass of barnacles, oysters and algae than those on the landward zone. This is due to less exposure to the air and the higher moisture content which reduces the rate of desiccation.

The nursery-ground value of mangroves and the importance for benthic macrofauna has long been stressed (Macnae, 1968). Therefore the finding that collection of the majority of the mollusc and crab resources was done in or close to mangroves was expected. The positive correlation between yield of prawns and area of mangroves is documented
worldwide (Turner, 1977). Terrestrial species—notably blue monkeys, bush pigs, birds, ants, bees and spiders—were also found in the mangroves.

SALT PRODUCTION

There are 30 salt works in Bagamoyo and the best season for salt production is from August to March. During the long rains (April to June) salt operations stop and the reservoir and crystallisation ponds may be used for fishing (Semesi et al., 1998). The price of salt fluctuates from TSh. 1000 to 2500 per 50kg bag. However, since the introduction of trade liberalisation, locally produced salt has faced stiff competition from less expensive imported salt. Some salt works have stopped production due to lack of market and space to store the unsold salt (A. Raisi, pers. commun.).

Several species of fish and prawns were identified in the lagoon from which water is drawn to the salt ponds (Table 1). Most of the fishes were juveniles.

A high abundance of the brine shrimp *Artemia salina* was found in the crystallisation ponds in both Kingani and Stanley saltworks. However, this resource remains unexploited although elsewhere it is used as a food source in aquaculture (Rasowo, 1992). The presence of *Artemia* in salt pans enhances the quality of the salt produced. This is through the metabolites of *Artemia* which provide a suitable substrate for *Halobacterium*. This bacteria assures the red water coloration in the crystallisation pans, thus enhancing heat absorption, which in turn promotes the production of bigger and finer salt crystals.

<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Liza</em> sp.</td>
<td>Mugilidae</td>
<td>Mullets</td>
</tr>
<tr>
<td><em>Scarus</em> sp.</td>
<td>Scaridae</td>
<td>Parrotfish</td>
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<tr>
<td><em>Gerres</em> sp.</td>
<td>Gerreidae</td>
<td>Silver biddies</td>
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<tr>
<td><em>Terapon jarbua</em></td>
<td>Terapontidae</td>
<td>Jarbua terapon</td>
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<tr>
<td><em>Carangoides</em> sp.</td>
<td>Carangidae</td>
<td>Trevally</td>
</tr>
<tr>
<td><em>Arius</em> sp.</td>
<td>Ariidae</td>
<td>Sea catfish</td>
</tr>
<tr>
<td><em>Lagocephalus</em> sp.</td>
<td>Tetraodontidae</td>
<td>Pufferfish</td>
</tr>
<tr>
<td><em>Lutjanus</em> sp.</td>
<td>Lutjanidae</td>
<td>Snappers</td>
</tr>
<tr>
<td><strong>Prawns</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Penaeus monodon</em></td>
<td>Penaeidae</td>
<td>Giant tiger prawn</td>
</tr>
<tr>
<td><em>P. indicus</em></td>
<td>Penaeidae</td>
<td>Indian white shrimp</td>
</tr>
</tbody>
</table>

Birds of various types were found feeding on the areas of the salt works. These include: mangrove kingfisher, pied kingfisher, little egret, dimorphic heron, common sand piper, white pelican, greater flamingo, black winged stilt and little stilt. Fiddler crabs, *Uca* spp., were also found on the edges of the ponds. Fourteen species of microalgae were also identified in the salt ponds and these belonged to the genera *Oscillatoria,*
Spirulina, Lyngbya, Richelia, Nostoc, Pleurosigma, Gyrosigma, Hantzschia, Nitzschia and Euglena.

SEAGRASSES

Seagrasses are flowering plants belonging to the monocotyledons (den Hartog, 1970) restricted to shallow marine waters that allow sufficient sunlight to penetrate, and grow best in lagoons and protected areas on muddy or sandy substrates. Seagrass beds are very productive areas and are high in species diversity and numbers of individuals (Phillips and Menez, 1988). Beside providing shelter for juveniles of a variety of organisms such as fish and prawns, they are eaten by many animals such as invertebrates, fishes and the endangered green sea turtles and dugongs. Seagrass leaves support sessile invertebrates such as bryozoans, cnidarians, sponges and tunicates that compete with algae for space (Semesi, 1988; Harlin, 1994).

All the species of seagrasses found in Tanzania were found in the sampled area except Enhalus acoroides. In the upper intertidal area, Halodule wrightii and Halodule uninervis were the dominant seagrasses and some Halophila ovalis was also found. In the mid-littoral zone Thalassia hemprichii and a mixture of Cymodocea rotundata and C. serrulata were the dominant species. Thalassodendron ciliatum and Syringodium isoetifolium occupied deeper pools and subtidal areas. In larger and deeper pools the seagrass Thalassodendron formed almost 100% cover and here rich assemblages of both flora and fauna were seen. Thalassodendron ciliatum carry many epiphytes: Jania adherens, Gracilaria corticata, Galaxaura, Ectocarpus sp., Enteromorpha clathrata, Ulva pulchra and Ulva reticulata, and several unidentified filamentous and calcareous algae. Usually Thalassia seemed to grow best in sandy/muddy areas exposed at low tide but Thalassodendron was found in coarse sand and on coral rubble not exposed at low tide.

Seagrass beds in Bagamoyo are heavily utilised as fishing grounds by artisanal fishermen and commercial trawlers. The major threat to Bagamoyo seagrasses is destruction by trawlers whose nets are dragged over the bottom and uproot seagrasses. In some occasions up to 80% of prawn bycatch is seagrasses (G. Msumi, pers. observ. at Mbegani).

SEAWeed

The term ‘seaweed’ traditionally includes only macroscopic, multicellular marine red, green and brown algae which are also referred to as macroalgae (Jaasund, 1976; Mshigeni, 1992; Trono, 1997). They occur in a variety of shapes and sizes and are classified according to colour. Plant pigmentation, light exposure, depth, temperature, tides and seashore characteristics combine to create different environments that determine the distribution of nutrients and variety among seaweeds. Most herbivorous fish depend on algal resources for food. On healthy reefs, the biomass of macroalgae is kept low by grazers and thus
they contribute a major proportion of the total production. However, it is the sparse mats of fast-growing, opportunistic filamentous algae that are usually responsible for the high primary productivity per unit area in most coral reefs. Calcareous algae are predominant contributors to both the bulk and frame structures of the majority of reef limestone deposits (Björk et al., 1995).

In contrast to seagrasses, seaweed have many direct uses. Seaweed can be eaten by humans as food (Semesi and Dawes, 1984; Trono, 1997) and are sources of useful industrial products such as phycocolloids: carrageenan, alginates and agar (Mshigeni and Semesi, 1977; Semesi, 1981). Algal phycocolloids find use in the food industry as thickening and emulsifying agents. Some of the algae are used to prepare soil conditioner for horticulture. Other uses include medicine, animal feed, cosmetics, and fish bait (Chapman, 1970; Mtolera and Semesi, 1992; Trono, 1997).

In Bagamoyo seaweed are used directly as fish bait but not for the other uses. The species used as fish bait include Laurencia papillosa, Chaetomorpha crassa, Dictyosphaeria sp. Cladophora sp., Boodlea sp. and unidentified algae locally known as ‘mwani wa tasi’. Other algae reported by local fishermen as fish bait but not yet identified are: ‘mwani msaika’, ‘mwani kanju’, ‘mwani mkuvi’, ‘mwani uchili’, ‘mwani kalala’, ‘mwani kibarashuti’, ‘mwani muungaye’, ‘mwani devu’, ‘mwani pombo’, ‘mwani chagamwa’ and ‘mwani saga’. From October to December ‘mwani wa tasi’ is present in large quantities, and fishermen from Zanzibar seasonally immigrate to the Bagamoyo area to collect it. The amount of algal fish bait used per basket trap varies from 1–4 kg depending on the size of the trap. Each fishing boat carries about 30kg a day of algae to use as fish bait. When algal availability is low, fishermen usually mix algae and brittle stars (ophiuroids), known locally as ‘chanjamaji’, for fish bait. Some of the seaweed species found in Nunge Bagamoyo are shown in Table 2.

Algal species showed sharper seasonality than seagrasses which form perennial stands. For example, in July Hypnea musciformis and Graciaria corticata dominated as epiphytes on Thalassodendron but in November Jania sp. was the dominant epiphyte. Of the blue-green algae (also referred to as Cyanobacteria), Lyngbya sp. was very common, especially in muddy habitats. The planktonic cyanobacteria Trichodesmium spp. blooms were also noted in December and March.

CORAL REEFS

Coral reefs are well known for their high productivity. Therefore in Bagamoyo, coral reefs are the main fishing grounds of artisanal fishermen. Mwambakuni which is about one hour by a 25 Hp boat engine from Bagamoyo town is visited by many fishermen who fish and collect sea cucumbers and shells. Tourists also visit the area and a large part of it is exposed during low tide. The part that is exposed during low tide is composed of either sand or seagrasses, mainly Thalassia hemprichii and Halodule sp. In the shallow tide pools Thalassodendron seagrass predominate with a rich species of eels, crabs, seacucumbers, starfish and many molluscs. In the wave-exposed areas, big Porites
Table 2. Macroalgae collected at the intertidal area at Nunge, Bagamoyo

<table>
<thead>
<tr>
<th>Green algae</th>
<th>Brown algae</th>
<th>Red algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halimeda macroloba</td>
<td>Spatoglossum asperum</td>
<td>Acanthophora muscoide</td>
</tr>
<tr>
<td>Halimeda discoidea</td>
<td>Padina gymnospora</td>
<td>Acanthophora spicifera</td>
</tr>
<tr>
<td>Ulva reticulata</td>
<td>Hormophysa triqueta</td>
<td>Amansia glomerata</td>
</tr>
<tr>
<td>Ulva fasciata</td>
<td>Sargassum spp.</td>
<td>Amphiroa aniceps</td>
</tr>
<tr>
<td>Boergesenia forbesii</td>
<td>Cystoseira myrica</td>
<td>Botryocladia leptopoda</td>
</tr>
<tr>
<td>Neomeris van-bosseae</td>
<td>Cystoseira trinodes</td>
<td>Gracilaria salicornia</td>
</tr>
<tr>
<td>Anadyomene wrightii</td>
<td>Hydroclathrus clathratus</td>
<td>Gracilaria corticata</td>
</tr>
<tr>
<td>Bornetella oligospora</td>
<td>Calpomenia sinuosa</td>
<td>Gracilaria crassa</td>
</tr>
<tr>
<td>Cladophora spp.</td>
<td>Dictyota spp.</td>
<td>Sarconema filiformis</td>
</tr>
<tr>
<td>Boodlea composita</td>
<td>Turbinaria ornata var. serrata</td>
<td>Champa pavula</td>
</tr>
<tr>
<td>Chaetomorpha crassa</td>
<td>Ceramium spp.</td>
<td>Centroceras clavulatum</td>
</tr>
<tr>
<td>Spongocladia vauchriaeformis</td>
<td>Digenia simplex</td>
<td>Eucheuma striatum</td>
</tr>
<tr>
<td>Valoniopsis pachynema</td>
<td>Hypnea musciformis</td>
<td>Hypnea pannosa</td>
</tr>
<tr>
<td>Dictyosphaeria carvenosa</td>
<td>Hypnea cornuta</td>
<td>Halyptylon subulata</td>
</tr>
<tr>
<td>Caulerpa cupressoides var. typica</td>
<td>Calpomenia sinuosa</td>
<td>Halymena venusta</td>
</tr>
<tr>
<td>Caulerpa serrularioides</td>
<td></td>
<td>Liagora ceranoides</td>
</tr>
<tr>
<td>Caulerpa racemosa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udotea orientalis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

heads are seen. In other areas the brown algae *Sargassum* spp. and *Turbinaria* spp. are common. Major threats to coral reefs of Mwambakuni include: over-harvesting of fish, octopus, sea cucumbers and shells; dragging of bags and trampling by fishermen during collection of shells and sea cucumbers; destruction by anchors; and fishing with dynamite. In addition to the above causes of reef destruction, at Mwambapwani and Mwambamjini the reefs are also destroyed by coral mining for building and sediment brought in by the Ruvu River. These threats are similar to those reported for other reefs in Tanzania (Bryceson, 1978; Wells, 1988; Linden and Lundin, 1996).

**FINFISH RESOURCES**

The popular fishing grounds in Bagamoyo are Mshingwi, Mwambakuni, off Ruvu River, Saadani and Mwamba Buyuni. About 1100 artisanal fishermen using 120 traditional vessels operate here. There are 10 prawn trawlers which compete and conflict with artisanal fishermen.

Fisheries statistics are very unreliable. Out of the eight landing stations, the catch of only two stations is recorded. For example, on the 26/12/96 and with the help of seven students we measured the fish landed by five boats at the Customs Landing station. The landing of the five boats totalled 498kg (99.6kg per boat) worth TSh. 256,900 (TSh. 51,380 per boat) at the auction. The catch per boat ranged from 58–154/kg/day. Seventeen species of fish were landed. Their local names were: ‘chewa’ (rock cod), ‘pono’ (parrot fish), ‘mchone’ (sweetlips), ‘tasi’ (rabbit fish), ‘changu’ (snapper), ‘chuchunge’
(half beaks), 'bobwe', 'taa' (ray), 'hongwe' (cat fish), 'janja' (snapper), 'kibua' (mackerel), 'kangu' (blue parrot fish), 'mkule' or 'mzia' (barracuda), 'pandu', 'kolekole' (jacks) and 'mkundaji' (goat fish). Also landed by these boats were 'ngisi mwanzi' (squid, long type) and 'ngisi dobi' (cuttlefish, short type). The 14/7/97 catch of 14 boats in the same landing station was also recorded. The fish landed by the 14 boats totalled 1046kg (74.7kg/boat) valued at TSh. 349,500 (TSh. 24,964/boat) at the auction market. We noted that the catch was not weighed although there was a weighing balance. However, we noted fishermen with bunches (called 'mitungo') of fish which had weights ranging from 0.9–1.4kg. Therefore an estimate of 'mitungo' could provide reasonable estimates of the landing.

From this small sampling we could show that the catch is composed of multi-species, and yield varies with season. Previous studies have shown up to 100 species caught in waters less than 20m in the area (Msumi, 1992; Semesi et al., 1998). However, the catch statistics in the Bagamoyo district indicate extremely low catches. The estimates of demersal fishes by M/V Mafunzo (1984–1991) which is owned by Mbegani Fisheries Development Centre, found the lowest biomass of 11kg/ha in February and March while the highest was in April, 53kg/ha, with an annual average of 27kg/ha (Msumi, 1992). Therefore inefficient recording of data and the fact that some fishermen avoid landing sites to evade paying taxes may account for the low figures.

The landing sites are very unhygienic and when we examined for the contamination of bacteria, we found that the tables used at the market had very high levels of E. coli. There is no safe water or toilets in the landing site and as such fish have to be fried or smoked immediately to avoid them going bad.

PRAWNS

The prawn fishing grounds of Bagamoyo cover an area of approximately 280km² (B. Kalangahe, pers. commun.). Prawn resources of Bagamoyo are exploited by the artisanal fishermen in shallow estuarine waters of less than 10m in depth. Table 3 depicts declining prawn landings between 1990 and 1996. Commercial trawlers (15–30m in length) operate at a depth of between 10 and 80m (W. Haule, pers. commun.).

There are five prawn fishing grounds in Bagamoyo: Payogo (near Kaole village), Mkadini, Kitame, Porokanya and Saadani. The artisanal prawn fishery (comprising mainly Penaeus indicus and P. monodon) is mostly concentrated in the nursery grounds, thus the catch from these areas is dominated by sub-adults (Subramaniam, 1980). It is generally reported that the highest catches for artisanal fishery are associated with the rainy season from September to April (Bwathondi and Mwaya, 1984; B. Kalangahe, pers. commun.).
Table 3. Production of prawns from the Bagamoyo artisanal fishery from 1990 to 1996

<table>
<thead>
<tr>
<th>Year</th>
<th>Landings (kg)</th>
<th>Value (TSh.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>10,146</td>
<td>11,187,272</td>
</tr>
<tr>
<td>1991</td>
<td>5388</td>
<td>2,816,630</td>
</tr>
<tr>
<td>1992</td>
<td>1072</td>
<td>663,124</td>
</tr>
<tr>
<td>1993</td>
<td>845</td>
<td>493,130</td>
</tr>
<tr>
<td>1994</td>
<td>860</td>
<td>835,055</td>
</tr>
<tr>
<td>1995</td>
<td>254</td>
<td>322,700</td>
</tr>
<tr>
<td>1996</td>
<td>185</td>
<td>319,500</td>
</tr>
</tbody>
</table>

(Source: Annual Reports, Bagamoyo District Fisheries Office).

Table 4. Selling prices in Bagamoyo for sea cucumbers in 1996 (dried weight) (USD 1 = TSh. 600 in 1996)

<table>
<thead>
<tr>
<th>Type</th>
<th>Price (TSh/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holothuria atra and Bohadschia vitiensis</td>
<td>15,000–20,000</td>
</tr>
<tr>
<td>Thelenota ananas and Holothuria scabra</td>
<td>5000–6000</td>
</tr>
<tr>
<td>Stichopus hermanni</td>
<td>5000–6000</td>
</tr>
<tr>
<td>Actinopyga mauritiana</td>
<td>3000–4000</td>
</tr>
<tr>
<td>Bohadschia sp.</td>
<td>1600</td>
</tr>
</tbody>
</table>

SEA CUCUMBERS

Sea cucumbers locally known as ‘majongoo bahari’ are not part of the diet of the local people, and this resource is collected as a ‘cash crop’ (Semese et al., 1998). The species of sea cucumbers harvested in Bagamoyo include: Holothuria scabra (‘pauni’), H. atra (‘jongoo maji’, ‘pesa’), H. nobilis (‘pauni nyeusi’), Thelenota ananas (‘spinyo’), T. anax (‘ngusa’/‘spinio mama’), Bohadschia vitiensis (‘barang’), Actinopyga mauritiana (‘mbura’/‘khaki’), A. miliaris (‘kijino’), and Stichopus hermanni (‘tairi’) (Table 4).

It was reported (Conand, 1997a) that for the period January to March 1996, Tanzania exported 73.8 metric tonnes of beche-de-mer worth HK$ 1,679,000 to Hong Kong. The total annual world catch is around 120,000 tonnes (wet weight), valued at over US$ 60 million (Conand, 1997b). According to Conand (1997b), Hong Kong is the largest world market followed by Singapore and Taiwan. These animals are characterised by low mobility, which makes them particularly susceptible to over-harvesting.

SHELLFISH

The term shellfish is generally applied to all invertebrate marine organisms having visible shells. Certain species are of direct or indirect commercial importance to humans. Most bivalves contribute to the organic turnover in the intertidal (littoral) zones of marine waters. Others are a source of food for many cultures and therefore play an important role in the fishing industries of many countries.
<table>
<thead>
<tr>
<th>Local name</th>
<th>Scientific name</th>
<th>Use</th>
<th>Habitat and season</th>
<th>Other comments given by women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kombe kicha</td>
<td><em>Anadara natalensis</em></td>
<td>Meat</td>
<td>Found in mudflats associated with seagrasses throughout the year</td>
<td></td>
</tr>
<tr>
<td>Kombe kizungu</td>
<td>or Kombe kawaida</td>
<td>Meat and operculum</td>
<td>Found in mudflats associated with seagrasses throughout the year</td>
<td>Its meat has lots of sand</td>
</tr>
<tr>
<td>Nyaluale</td>
<td><em>Strombus gibberulus</em></td>
<td>Meat</td>
<td>Found throughout the year in sandy habitats</td>
<td>Its meat is tough. It can be detected by looking at raised mud/sand area. A metal rod called 'mkunjo' is used for collection</td>
</tr>
<tr>
<td>Kinyonga</td>
<td><em>Polinices mammilla</em></td>
<td>Meat and operculum</td>
<td>Found throughout the year in sandy habitats</td>
<td>Very common; its meat preferred by many</td>
</tr>
<tr>
<td>Kijino</td>
<td><em>Nassarius arcularius</em></td>
<td>Meat and operculum</td>
<td>Sandy and muddy areas, dominant during the southeast monsoon, mostly found at night</td>
<td>It has soft meat and it is detected by looking at raised mud/sand area. A metal rod called 'mkunjo' is used for collection</td>
</tr>
<tr>
<td>Kikola or Kikora</td>
<td><em>Murex brevispina</em></td>
<td>Meat</td>
<td>Sand and intertidal pools</td>
<td></td>
</tr>
<tr>
<td>Kome</td>
<td><em>Pleuroloca filamentosa</em></td>
<td>Meat and operculum</td>
<td>Sand and intertidal pools</td>
<td></td>
</tr>
<tr>
<td>Kome</td>
<td><em>Pleuroloca trapezium</em></td>
<td>Meat and operculum</td>
<td>Sand and intertidal pools</td>
<td></td>
</tr>
<tr>
<td>Suka or Tondo</td>
<td><em>Terebraia palustris</em></td>
<td>Meat for man and fish bait</td>
<td>Found throughout the year in mangrove areas</td>
<td>Avicennia leaves attract this species</td>
</tr>
<tr>
<td>Fundura</td>
<td></td>
<td>Meat</td>
<td></td>
<td>Very depleted</td>
</tr>
<tr>
<td>Madamudamu</td>
<td><em>Cypraeccasis rufa</em></td>
<td>Meat</td>
<td>Low quantities, also eaten by dolphins</td>
<td></td>
</tr>
</tbody>
</table>
Women and children are the main collectors of shellfish for food in Bagamoyo (Table 5). Women can collect up to 25kg a day of shellfish by hand. This is done two weeks a month during the spring tides. The moon calendar when collection is carried out is referred to in Kiswahili as ‘mwezi 12 hadi 19’ and ‘mwezi 27 hadi Mwezi 5’. The full moon spring tides are the best time for collections and night collection can be done during this time. Other shellfishes are harvested as ornamentals and sold to tourists (Table 6).

Table 6. Common types of ornamental seashells harvested from Bagamoyo coast

<table>
<thead>
<tr>
<th>Local name</th>
<th>English name</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madondo/Madamu damu</td>
<td>Bull-mouth helmet</td>
<td>Shallow, sandy substrates close to coral reefs</td>
</tr>
<tr>
<td>Makururu</td>
<td>Tiger cowries</td>
<td>Under coral and boulders in shallow or deep water</td>
</tr>
<tr>
<td>Mliba</td>
<td><em>Ramosa murex</em></td>
<td>Shallow soft substrata</td>
</tr>
<tr>
<td>Nyangale/Madole</td>
<td>Common spider conch</td>
<td>Sheltered shallow waters</td>
</tr>
<tr>
<td>Viwangwa</td>
<td>Cone shells</td>
<td>Lower eulittoral, often under boulders</td>
</tr>
<tr>
<td>Baragumu</td>
<td>Giant triton shell</td>
<td>Among shallow coral sand</td>
</tr>
<tr>
<td>Shela</td>
<td>Harp shells</td>
<td>Shallow and deep sand</td>
</tr>
<tr>
<td>Mwezi mweupe/Honga</td>
<td>Moon shells</td>
<td>Sandy bottoms in shallow waters</td>
</tr>
<tr>
<td>Majeta</td>
<td>Giant clam</td>
<td>Embed partially in coral or rock in shallow waters</td>
</tr>
<tr>
<td>Kete/Simbi</td>
<td>Gold ringer</td>
<td>In shallow water, tide pools, under stones or amongst seagrasses</td>
</tr>
</tbody>
</table>

(Table Modified from Bwathondi and Mwaya, 1984 and Richmond and Rabesandratana, 1997).

LESSONS LEARNED

We summarise here the lessons learned from the 3-year study of Bagamoyo coastal resources.

- Human capacity building and working with a large interdisciplinary team takes time. This is because people have to learn to work together and it is sometimes difficult to accommodate everyone’s needs, such as the timing of fieldwork.
- Involving students in carrying out research is easier than government personnel because the latter are busy with many other responsibilities. However, involving government personnel raises their awareness and enables them to understand the resources better. In Tanzania most natural resources officers in the local governments are not trained on coastal and marine resources. For example the three foresters responsible for Bagamoyo mangroves have not received formal training on mangroves and are not well versed with the complexity of the ecosystem. As such almost all their trial planting of mangroves failed because of lack of understanding of the ecological requirements of mangroves.

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— We all learned from each other and with time, communication among researchers improved and the network became quite strong.
— Marine scientists and resource managers can gain new insights through dialogue and collaboration with coastal inhabitants in the research process. Consequently, new research questions can be identified and the scientific analysis can be improved.
— Through our efforts to raise awareness on Bagamoyo resources, more researchers are now being drawn to work in Bagamoyo. For example, a project entitled ‘Flux and Impact Processes in Mangrove Ecosystems’ will be carried out by an interdisciplinary team involving botanists, zoologists, chemists and microbiologists from the Netherlands and the Faculty of Science, University of Dar es Salaam with Netherlands government support.

RECOMMENDATIONS

Since little is known of the role of most commercially harvested species such as sea cucumbers and molluscs, the development of fisheries without this knowledge is dangerous in terms of maintaining ecosystem processes. The general recommendation is to continue with an interdisciplinary study to understand the biology, ecology and population dynamics of the various species and also the socioeconomic factors influencing their harvesting.

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REFERENCES


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Impacts of tourism on the activities of the women of the southeast coast of Unguja, Zanzibar

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ABSTRACT

This paper is concerned with a discussion of tourism and rural livelihoods in a coastal area of Zanzibar, namely the southeast coast of Unguja. The focus of the paper is on women and addresses the issue of how tourism affects their activities in the coastal zone. More specifically it investigates issues concerning the impact of tourism on natural resource use, and the issues concerning access to natural resources by women. Furthermore, the discussion explores whether there is a contradiction between women’s activities and the interests of tourism. In addition, the paper discusses the new opportunities for income generation that the tourist market might provide for women, both in formal type employment arrangements and in informal sector activities, such as handicraft production.

INTRODUCTION

Tourism has long been recognised for its dynamic character and economic potential for boosting trade and opening up regions that lag behind in their development. According to Frangialli (1999), tourism in the 21st century will be the world’s biggest industry. The majority of tourist receipts go to developed countries, but the developing countries’ share has been rising steadily since the late 1960s (World Tourism Organisation, 1993). Frangialli (1999) further argues that along with its phenomenal growth and size, the tourism industry will also have to have more responsibility for its extensive impacts, not only its economic effects, but also the impacts on the environment and societies of host populations.

To the host population, tourism is often a mixed blessing. Tourism is bound to bring about changes in society, since it is a powerful medium affecting change (Smith, 1977). These changes can be both socioeconomic and cultural as well as changes in access to and use of the natural resource base, which many people in the Third World are dependent upon for their livelihood. This paper elaborates on some of the changes.

As in many other developing countries, Zanzibar has identified tourism as a major investment area. In recent years the number of tourists coming to Zanzibar, and especially the largest island Unguja, has increased rapidly. There was an average growth rate of 18.5% per annum from 1982 to 1992 (COLE and CoT, 1994). The total number of arrivals
increased from about 23,000 in 1986 to about 86,500 in 1998 (ZSD, 1998). The presence of tourists has become an important feature in the everyday life of many Zanzibaris, in both rural and urban areas. When the rationale for tourist development is discussed within Zanzibari Government circles it is often conceived in macroeconomic terms: generation of foreign exchange, government revenue and employment. These benefit the whole of Zanzibar. However, this paper is more concerned with how tourism affects local communities and especially women.

METHODOLOGICAL APPROACHES

This paper is based on data collected by H.B. Wallevik together with Grete Benjminsen for an MSc thesis entitled ‘Tourism in Zanzibar — A Fool’s Paradise?’ which examined the impacts of tourism on livelihood security of the people of the southeast coast of Unguja. The information was gathered from three different villages, namely Paje, Bwejuu and Michamvi, during the period August–December 1997. Different qualitative research methods were used in the data collection, participant observation, qualitative, namely interviews, both individually and in groups, informal discussions and literature review. During several stays in Zanzibar from 1994–1999 valuable general information on Zanzibar was obtained, and over two additional periods in Zanzibar, in 1998 and 1999, information specifically on women was gathered. During all periods of data collection N. Jiddawi was the local supervisor and contact person. Her knowledge about women in coastal areas of Zanzibar is incorporated in this paper.

Women as income earners for the household economy

Traditionally in Unguja, men are the providers for the household. There is a strong link between masculinity and the ability to provide the household with its needs. However, this seems to be changing. With the rising cost of living it is becoming increasingly difficult for one person to earn enough money to provide the household with what it needs. Hence women seek alternative means of income and contribute with cash income to the household economy.

Along the southeast coast of Unguja women have always been important contributors to the household, for example by providing agricultural products from their subsistence farming activities. They have also had access to some cash income through traditional women activities. Over the last 10 years, however, women have had access to their own steady income through seaweed farming. This has resulted in more and more women turning to seaweed farming instead of cultivating agricultural products. Seaweed farming provides women with regular cash income and it has been argued that it has had a relatively important effect on household economies (Jiddawi and Ngazy, 1998; Shechambo et al., 1996; Eklund and Pettersson, 1992).

The income derived from seaweed farming has enabled women to assume a greater responsibility for the household economy. Furthermore, when women get access to their own regular income they have an opportunity to negotiate on household needs.
This can be understood in the view of Moore (1992) who argues that there always is a negotiation on needs within a household. Household members, be it men or women, young or old, see things differently and hence define household needs differently. Consequently, when women get access to their own income they are in a better position to negotiate on household needs. On the other hand Caplan's work on the island of Mafia (situated a little further south from Zanzibar) shows that the autonomy exercised by women is related to and limited by adherence to an Islamic moral code. Even though women are able to obtain an income independently through their own activities, they are still limited by marital obligations and the absence of male child support (Caplan, 1975, 1984, 1989, 1995).

Access to income has made it possible for women of the southeast coast to allocate money on things they perceive as needs. Men accept that income derived from seaweed farming is spent on what women feel is important. Many women have invested in other projects, be it a new house or other durable items such as sewing machines or deep freezers. Cash income is also spent on common household needs like clothes, health and education. All in all, contemporary household economies also depend on women's access to cash income.

Women's roles are important to rural livelihoods, and how women are impacted by the introduction of tourism raises a number of issues. Will the tourism and women have conflicting interests or is co-existence possible? Can tourism even give women an additional chance to increase their income and hence further secure livelihoods?

Female activities of the southeast coast
The southeast coast is one of the main tourism zones in Unguja. The northern boundary of the tourism zone is the tip of Ras Michamvi and its southern boundary is the southern border of the village of Jambiani. The southern part of the area is reserved for local guesthouse projects, while the northern part is set aside for construction of high-class hotels. Since the late 1980s there has been hotel development in the area, and both local guesthouses and high-class hotels are present. Since the area is relatively poor in terms of arable land, the people depend mostly on marine resources for their livelihood.

Women are engaged in several activities, but in general their main survival depends on the available natural resource base. As mentioned, agriculture was a very important activity for women at the coast, but after the introduction of seaweed farming there has been a tendency for more and more women to leave agriculture in favour of seaweed farming (Pettersson-Löfquist, 1995). However, some women are still engaged in agriculture either alone or as a joint activity with their husbands. Apart from seaweed farming, activities such as coconut husking, octopus hunting and collection of shells and sea cucumbers are typical female activities, and they are carried out on the beach and in tidal flats during 'bamvua' (spring tides) (Jiddawi, 1995). Women also make 'makuti’ (roofing material) and baskets from palm leaves.
In addition women carry out other income-generating activities such as handicraft production. Making of ‘kofia’ (Muslim hats), ‘mikeka’ (mats) and ‘mikoba’ (bags) are also typical additional sources of income for women. Furthermore, they are engaged in cooking food for sale, sale of juice, ‘barafu’ (ice-cubes) and ‘malayi’ (frozen juice). Activities like painting of ‘hina’ (hand make-up) and plaiting of hair are also typical women activities. Some women also sew clothes and sell ‘khangas’ (cloth wraps) from their homes.

The same places where women carry out many of their daily activities are also attractive to tourists. Women depend on access to beaches, tidal flats and coral reefs, the same areas used by tourists, but for different reasons. Tourists come to the coast to lay in the sun, swim in the sea and dive on the coral reefs. This issue reveals what might be understood as conflicting interests between women and tourists when it comes to natural resource use.

Impacts of tourism on natural resource use

Beyond the shoreline there are shallow tidal flats where women cultivate seaweed. The beaches are also associated with broad fringing reefs, which often are exposed at low tide. The reefs contain a colourful and diverse marine life. The existing artisanal fishing activities are varied and largely reef-dependent, and include collection of shellfish, crabs, lobsters and octopus. Women are involved in this collection and indeed hunting for octopus is a traditional task for women. These activities are carried out parallel with other activities on the tidal flats. Both shell collection and octopus fishing is vital for livelihoods, and a very important source of protein for the families.

Although women are engaged in several activities, seaweed farming has maintained its position as their major income source. When seaweed farming was introduced 10 years ago only two villages in Zanzibar were engaged in its cultivation. Seaweed farming spread rapidly and today there are 53 villages engaged in the cultivation. In 1990 about 261 tons of seaweed were produced (Jiddawi and Ngazy, 1998). Annual production now is over 5000 tons. Women can on average earn about 30,000 Tsh. (US$ 50) per month during a good season. Consequently, it is crucial for women to secure their possibilities to carry on this activity in the future.

In this connection, it is important to raise a central issue. It is argued that seaweed farming has increased women’s security at the household level, and also for the communities as a whole. The question that needs to be addressed is whether this increase in livelihood security is looked upon in a long-term or short-term perspective. There is a potential risk involved in a change towards such a specialisation regarding income-generating activities. Seaweed farming is subject to external and other forces, such as producer’s price fluctuations, the possibility of seaweed being infested with disease and other factors, which can lead to a decline in production. Therefore, seaweed farming may lead to increased vulnerability. The fact that women are leaving their agricultural plots may also result in reduced security in the long run. However, village women argue that they have not abandoned their fields, but left them in the care of their husbands. Earlier, men and women used to work together on the ‘shamba’ (cultivated
The only difference was that men often cultivated for sale, while women cultivated for subsistence, but it was still a joint activity with shared responsibilities. The fact that women have left agriculture has not necessarily reduced their access to agricultural products. However, it has increased the workload for their husbands. Still, as already mentioned, some women also perform their own agricultural activities in addition to having seaweed plots.

Another important aspect is that there is a high degree of divorce along the Swahili coast (Landberg, 1986). The situation will be different for the increasing number of female-headed households, since this category of women is more vulnerable to a decline in seaweed farming. For them a shift from agriculture to seaweed farming was more of a risk. It gave access to cash, but some agricultural products still have to be bought.

**Exclusion or co-existence in the beach areas**

Land tenure regulations in Zanzibar state that villagers cannot be excluded from using the beach and tidal flats outside a hotel since the area is owned by the state and everyone is free to use these areas. There have been incidents though, where women have been asked to move their activities elsewhere due to hotel construction.

One such incident occurred when a high-class hotel was established in the area. Before the construction of the hotel local women used the beach and tidal flats for their activities. Just outside the shoreline where the hotel is situated, women had plots for the cultivation of seaweed. Before the hotel started operating, the seaweed farmers were asked to move their activities, because the management at the hotel wanted the area to be used exclusively by their guests. They wanted to provide the tourists with what they advertise, namely an ‘untouched and clean beach’. Women’s activities were believed to disturb that picture. Particularly, the management disliked seaweed plots, which left wooden sticks and strings, and therefore degrade the appearance of the tidal flats. Additionally, heavy waves or currents might wash away seaweed from the plot and result in it floating around in the water. This would spoil the idyllic picture of clean beaches and water.

Seaweed farmers did not complain about being asked to move. They moved their plots and continued cultivation of seaweed elsewhere in the ‘shehia’ (local name for a village’s administrative boundaries). However, the compensation given to them was a precondition for them accepting to move. Seaweed farmers did not perceive this as a problem at the time of removal, and probably it was not a problem. However, it is a concern and the problem can worsen, if tourism increases. If hotels occupy large parts of the village shoreline and seaweed farmers are asked to move in return for compensation, this problem will be a fact. Similar cases of compensation to seaweed farmers have been reported in other coastal villages in Unguja (Haji, 1994; Dahlin and Stridh, 1996).

This situation does not only apply to seaweed farming. For instance further south in Kizimkazi, a similar conflict over land use has evolved. Women here claim that they have been excluded from using the beach for their traditional mosquito-net fishing. They need access to the tidal flats for fishing and argue that the increase in boats for dolphin tourists is the reason for them experiencing an exclusion from these areas (Ali et al., 1999).
In the study area there seems to be a very clear pattern in that it is only foreign-owned high-class hotels that prefer to evict villagers from the use of areas adjacent to hotels. Seaweed farming is also practised around guesthouses and the strategy here is for guesthouse owners to explain to their guests about the local activities going on in the tidal flats, instead of compensating the seaweed farmers to move. Tourists at local guesthouses seem to enjoy watching the villagers doing their tasks, and even assist them in their work. This only reveals that the impacts of tourism are fundamentally different, depending on the prevalence of guest houses or high-class hotels.

There might be other reasons for constraints regarding seaweed farming. In the beginning, one reason for seaweed farming being a woman’s activity was the little income that could be obtained from seaweed farming, relative to other male activities. However, it has been brought to our attention that there is a tendency for men to become more involved in seaweed farming as an alternative to fishing, mainly due to diminishing fish stocks (comment by anonymous reviewer). If men are turning to seaweed farming as a result of declining fish catches, tourism is indirectly a part of this explanation. Jiddawi et al. (1995) list several possible reasons for the general decrease in fish stocks in Zanzibar over the last few years, including improper fishing methods, sewage pollution, increased sedimentation, turbidity and siltation. Tourism also seems to bear some responsibility for the decreased access to fish, since it has greatly increased the demand for fish. Furthermore, fishing activity by local fishermen has increased because they want to maximise their profits. Apart from increased demand for marine resources such as food, tourism may also exacerbate certain destructive activities such as shell collection, coral mining for hotel construction, boat anchoring when scuba diving, and fishing in coral reefs areas. However, the decrease in fish stocks cannot be blamed on tourism alone and in the final analysis a shift towards seaweed farming for men will have an implication for women and their access to income.

Loss of access through sale of coconut trees

The beach area is the workplace of women and it is used extensively. Here women also carry out other activities, for example, coconut husking. Women bury the husks from coconuts along the beach where they are left to rot, and after 6–12 months the husks are dug up. The husks are then beaten until they are a thready mass and then twined into ropes. The ropes are sold to traditional bed makers, fishermen, and are also used in house construction, at a price of 10 Tsh. per ‘pima’ (one length) of coir rope. This activity used to be the most profitable occupation before seaweed farming (Ako, 1995). Nowadays it is considered a subsidiary activity, but women still earn some income from this.

Coconut tree products are used for multiple purposes. Apart from using the coconut husks for rope making women use the coconut tree products for making roofing material and baskets out of the palm leaves, while the coconut milk is used for cooking. Residues are also used for firewood. Hence, the coconut tree is a vital resource for women, and
they need access to it. Women stated that in the past there used to be a surplus of trees and they had free access to coconut tree products. With the introduction of tourism this has changed, since many villagers have sold their coconut trees to hotel investors.

In Zanzibar the government owns the land. However, coconut trees can be owned individually. It has always been important for villagers to own coconut trees since it is regarded as the best way to establish a claim to land (Middelton, 1961). Owners of coconut trees can freely use the land surrounding the trees. The chief means of acquiring trees along the Swahili coast are through inheritance, purchase and planting (Caplan, 1995).

In the study area it is mostly men who own coconut trees. Although women according to Islamic law can also inherit trees they can only inherit half of what men inherit. Some women use their income to purchase coconut trees to ensure access to land and coconut tree products. In the areas near the beach, however, the trees have become very expensive. Pettersson-Løvquist (1995) predicted that as land became scarcer, the value of the coconut trees would increase. This has in fact been the case, and today trees are often sold for up to 60,000 Tsh. (about US$ 100) each. Another way, for both men and women to obtain access to trees is by planting them. Krain et al. (1993) argue, however, that due to low survival rates of newly-planted coconut trees, no significant increase in the number of trees can be expected in the future.

After the introduction of tourism many trees, especially those on the shoreline close to the beach, were sold to tourism investors. Women have experienced that through the sale of coconut trees to investors, they have lost access to coconut tree products. Those women who no longer have access to palm tree products are suffering from the high market prices for these products. In addition, some women have lost their former income-generating activities, which were based on these products, such as making and selling roofing material and coir ropes.

In the past villagers have used the land surrounding the coconut trees as pathways, plots for houses, graveyards, storing fishing equipment and drying seaweed. Tourism has also brought about changes in this sense. Since villagers sell their coconut trees to non-villagers this also implies that the villagers are no longer entitled to use the areas as before. In many cases investors have only bought a certain amount of the coconut trees at their hotel sites. Consequently, the tree owners who did not want to sell are allowed to freely enter the site and harvest products from the trees as before. It is, however, a concern that when trees are bought by investors the hotels are often fenced in. In most cases therefore the villagers are not legally, but physically, excluded from the site. This has affected the villagers' movement and working patterns. It leads to longer walking distance to their seaweed plots, fishing spots etc., since the route to the beach is closed. Pettersson-Løvquist (1995) reports that villagers fear that their route to the beach might become entirely closed as more projects are established. Naturally this also affects women. Due to their multiple activities in the beach area combined with household responsibilities, women walk back and forth to the beach many times a day.
A greater differentiation at village level?

In his study in Paje, Pettersson-Lofquist raises another possible consequence of tourism in these local communities. He states that “there is a possible future conflict arising between the individual villagers owning coconut palms along the coastal strip and the interest of the community as a whole” (1995:10). The ‘uko’ that first came to the area planted the trees at the beach. When other people moved in there was an extension of the area and trees were also planted inside the village. There were enough trees in the area and the villagers traditionally shared the resources including land.

One can say that the introduction of tourism in the area has confirmed the importance of belonging to the different ukoos. Since prices of coconut trees situated at the beach have increased it has become important to identify the owners of trees. Now, there is a gap between tree-owning ukoos and those who do not. A community, which in the past shared resources is now about to change, and private ownership of trees has become increasingly important.

Conflicting interests?

In the future there might be a space problem at the beach and on the tidal flats. Women need to continue using the beach for their traditional activities such as coconut husking. On the other hand, tourists require an open beach for sunbathing and other recreational activities. Also, in term of access to the tidal flats there might be a conflict between the women who want to continue cultivating seaweed, collecting seashells and hunting for octopus, and tourists who want to swim, sail and snorkel.

According to government guidelines for investors in the tourist industry (Smith, 1994), local people’s traditional economic activities should always co-exist with tourist activities wherever this is possible. If this is deemed to be impossible, the reallocation of local activities should only be done by agreement with the local people and the investors concerned. This type of agreement often includes compensation as in the case with the seaweed farmers referred to above. However, this has only been reported in areas near high-class hotels. Especially near guesthouses, a pattern of sharing the use of the beach and tidal flats among villagers and tourists seems to have emerged. The villagers use the areas for their activities when the tide is out, while the tourists enter the scene at high tide for sunbathing and swimming. Here, another conflict arises.

Making the private public

The introduction of tourism in an area also implies contact between the local population and tourists. This contact can be both negative and positive (Smith, 1977). The sharing of the beach area implies some negative effects for women. According to Muslim rules, strict dressing codes are exercised. One should wear clothes that cover the knees and

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1 The people who perceive themselves as the Hadimu inhabit the southeast coast. The widest Hadimu kinship group is the ‘uko’. The ‘uko’ consist of all the descendants through both men and women of a common great grandfather (Middelton, 1992).
shoulders, and wearing transparent clothes is not acceptable. If certain parts of the body are seen, that person is considered to be naked. Women in particular cover themselves by wearing clothes from head to toe. On the other hand, tourists who come to the coast to enjoy the sun and sandy beaches have quite the opposite view of nakedness. For them wearing a bikini is considered to be acceptable. However, we are dealing with a society where the locals look upon nakedness as something strictly reserved for the private sphere, or in the words of one of the local girls: *sisi ni watu wa siri*, meaning ‘we are people of secrets’. With that in mind, the implication of the introduction of new behaviour should not be underestimated. This is as Pettersson-Løfquist (1995:10) says “a delicate issue to balance the right of the tourists to enjoy their vacations ... and the community member’s right to defend their way of living”.

The beach area is the women’s working place. Having half-naked tourists in their vicinity is seen as offensive and reduces the quality of life according to the women. However, as long as the nakedness is in the tourism belt (referring to beach and tidal flats), the villagers seem to tolerate it and the women have in a way become used to tourists dressed in swimming costumes and scant clothing while on the beach. Women understand that tourists come to their villages to swim and sunbathe.

So far, in this paper, there has been a focus on negative impacts of tourism on women’s activities. It is misplaced, however, to only focus on these aspects, and to imply that tourism brings only negative impacts on host societies (Smith, 1977).

**New opportunities for income generation within the tourist sector**

Many critics of tourism-related development are particularly impressed by its potential to generate employment (Farver, 1984). Cukier (1996) asserts that it is the increase in employment opportunities which may be of prime economic importance to local populations.

In general, introduction of tourism in the area has given villagers new income opportunities. The question here is what kinds of opportunities are there for women when it comes to employment in tourism and what kind of constraints they meet. New opportunities for income generation for women within the tourist industry have to be divided into those opportunities women have in formal employment arrangements, and the opportunities for income generation within the informal sector.

**Choices and constraints within formal sector employment**

When it comes to formal sector employment women are constrained by lack of experience in the tourist business, which is necessary, especially in high-class hotels, and lack of language skills (mainly English). In addition, many high-class hotels recruit their personnel from Zanzibar Town or from the mainland. This excludes local women from having jobs in high-class hotels. The picture is a little different when it comes to employment in local guesthouses. There are women without any experience working in the guesthouses, but they are also here excluded from having well-paid jobs, and
this is often due to lack of skills in English. According to Harrison (1992) there is a tendency in the tourist industry everywhere, for women especially to carry out many of the lower status jobs in the tourist hierarchy. Sharpe (1984) argues that women tend to remain concentrated in occupations that are predominantly female. In general, on the southeast coast, the jobs held by women are typically 'female' tasks such as cooking and cleaning. Even so, women employed in hotels earn between 15,000 and 30,000 Tsh per month and this new income opportunity has given them a chance to contribute to the household economy, just as income from seaweed farming has done.

This also leads to a discussion on livelihood security in the long term. Women working in hotels often leave other income-generating activities. Hence, these women become totally dependent on the income derived from tourism. The risk involved is clear, bearing in mind the fickle nature of the tourism industry. What alternatives do these women have when tourism no longer provides an alternative income? Village women say that they will return to seaweed farming. Women that are not engaged in the formal tourist sector use the argument of a diversified economy when talking about opportunities for income-earning activities in tourism, and why they do not explore them.

Lack of language skills is not the only obstacle women face when it comes to tourism employment. In Zanzibar an important marker of distinction is gender. According to Larsen (1990, 1995) women and men operate within different spheres, the private and the public sphere. The traditional division of labour into public and private spheres also has implications for women wanting to work in the tourist industry. Due to Muslim rules and norms there has been much discussion as to whether or not women should work in hotels. According to traditional norms women in the villages should not, to the same extent as men, be exposed to tourists. In most of the hotels and guesthouses it is men who work in those positions dealing directly with tourists.

Tourist sites seen as 'free zones' where traditional values are challenged
Tourism facilitates the spread of western norms and values (Harrison, 1992) and hotels may come to symbolise 'modernity' (Wood, 1984), while as centres of entertainment they are attractive, especially to the young. The result is that young people are exposed to foreign influences, which prevail in tourist establishments. The opinion among adults and elders, in the study area, is that tourist sites may be seen as 'free zones', where the public and private spheres are not as distinct as in the village context, and where traditional rules and norms for behaviour are absent. Lack of this distinction in the hotels is according to many villagers due to the tourists influencing the locals. Influenced by western ideas, people from outside come to work in the hotels. In addition, other employees are from Zanzibar Town and they have been exposed to tourists and western influence for a longer period of time, and may have adopted some of their characteristics.

Contact with tourists leads to a contact between the sexes which is completely different from the way the locals behave in the village. The fear of changes caused by dress and
behaviour codes, such as public affection or consumption of alcohol makes a lot of the elder villagers reluctant to let their unmarried children, especially girls, work in hotels. In one of the villages the ‘sheha’ (village headman) and ‘watu wanne’ (his assistants) decided to forbid the ‘waris’ (unmarried girls) to work in a hotel due to lack of respect for traditional rules and norms in these places. The fear of tourist behaviour is related to the fear of loose relations between young people of the opposite sex, either among the locals or those coming from town, including the ‘papasi’\(^2\). When it comes to girls a fear often expressed is that if they are employed in hotels or guesthouses they might end up pregnant.

When seaweed farming was introduced it altered the relations within the household since women got access to cash income, and hence greater possibilities for negotiation on needs. However, it did not alter the basic traditional division between men and women’s activities. The activity soon became a woman’s task, mainly due to men’s responsibilities within the household to provide an everyday income for household needs. It could therefore more easily be adjusted to the existing cultural context and did not challenge rules and norms for behaviour. It is somewhat different with the introduction of tourism. However, some men and women claimed that they would let their daughter, even if unmarried, work in a hotel because the job was considered easy compared to traditional ways of making a living. Experience from a hardworking way of life made women decide that it would be better for their children to work in a hotel than to follow in their parent’s footsteps.

**Women and informal sector participation within the tourist sector**

It has been argued that the informal sector provides important avenues of income generation and accumulation for women, who have traditionally suffered from restricted access to formal education and formal sector employment (Narayan, 1997). So how do women on the southeast coast exploit the new tourist market in the informal sector? Women are engaged in the informal sector, but they do not fully utilise the opportunities within the sector. Many of the informal sector activities carried out by women could attract tourists.

The easiest way of earning money from tourism is through additional activities that women already do. One such activity is painting of ‘hina’ (hand make-up) and plaiting of hair. Among tourists these activities have become very popular, and in Zanzibar Town women carry them out in beauty saloons. Women on the southeast coast have picked up this trend and offer these activities to tourists. The tourists are approached on the beach by young relatives of these women and are asked to come home for hina painting or a new hairdo. Some women are also engaged by guesthouses and called upon when tourists demand such skills. Women can earn quite a bit of money on hina painting and hairdressing. For tourists it costs between 1500 and 4000 Tsh. (US$ 2–7).

Another way of obtaining an income quite easily is selling food. Together with the sale of fruits and coconuts, children often sell home-made cookies to tourists on the

\(^2\) Swahili word for a type of persistent insect attracted to humans—now used to describe the beach boys in Zanzibar.
beach. Women also cook food and sell directly to guesthouses. The reason why women send children to the beach to sell cookies, or ask tourists to come to their homes to plait their hair is because women themselves, as stated, are more restricted to the private sphere and are not supposed to approach tourists.

In addition women also collect shells while out hunting for octopus. Tourists buy shells from souvenir sellers; hence women get some benefits from tourist demand for shells. Women can get from 200–500 Tsh. per shell and the income from sale of shells is a valuable additional income for women in the context of the rural household. However, this activity is discouraged in Zanzibar due to the impact that shell collecting is believed to have on the environment.

Women also reported as a benefit the small amounts of money from tourists taking pictures of them while working. The fact that women have not thought of benefits on a larger scale may indicate something about how different the tourist world is to them, and how little they know about the business of tourism.

**Traditional handicraft production as a new market**

As already mentioned, women have traditionally been involved in handicraft making, such as the sewing of ‘kofia’ (hats) and plaiting of ‘mikeka’ and ‘mikoba’ (floor mats and baskets). These products can be of interest to tourists. However, women have not yet exploited the new market that tourism brings, when it comes to handicraft production, and many women have not even thought about the idea of selling these products to tourists. This has to be viewed in the context as to how women perceive this work.

Women have traditionally worked with handicraft making in addition to their main activities in the beach areas and their household responsibilities. Handicraft making is a very time-consuming activity and these activities are carried out during afternoons when women gather to chat and relax. Hence, they are subsidiary income-generating activities for women. Therefore, a possible explanation might be as women in the villages already have many responsibilities in addition to their work it might be difficult to find more time for these activities without giving up on other things. Here the argument of a diversified economy is called into question. Those women who are not fully engaged in tourism business see the extra work they have to put in to benefit from tourism as a risk in that it may lead to the neglect of other tasks and make them more vulnerable. This is especially the case since activities related to tourism are so seasonally dependent.

Having said this, women stated that the most important explanation for them not fully entering the tourist market is because they are not supposed to approach tourists in the way that men do. Involvement in tourism implies increased contacts with the opposite sex. Women emphasise that the reason they do not exploit the opportunity of selling traditional handicrafts to tourists is simply because they have no one who can sell their products for them. Since women after all are more restricted to the private sphere, the informal sector is not as accessible for them as it is for men.
CONCLUDING REMARKS

It is important to make a distinction between the impacts of high-class establishments and local guesthouses at the village level since the impacts are so different. There is an ever-present risk that the very development of the tourism industry will lead to destruction and degradation of the natural resource base. The tourism industry depends on the natural environment, on which the women also traditionally depend for their activities. This applies to whether it is during construction of the hotel projects, or when these are operational. In addition, recreational activities for tourists very often lead to increased pressure and degradation of natural resources. Protection of the environment is crucial both for the tourist industry's sustainability, and also for the villagers inhabiting the area.

Access to natural resources is very important for women’s livelihood. Building of hotels can, in addition to degrading the environment, reduce access to the natural resources they depend on. Women need access to natural resources, and one has to avoid competition between the interests of women and tourists. If women experience space constraints in the beach area and tidal flats and hence cannot carry out their activities it would mean that a great many households would be severely impacted. Especially, access to land for continuation of seaweed farming is an important issue when discussing development of new hotels. This is the case since so many women are involved in its cultivation and it has had positive effects with regard to current livelihood strategies. This concern applies especially to the high-class hotels. As this paper has shown there are not so many conflicts around local guesthouses regarding access to beach areas. Here the cultural impacts are greater though.

While the tourist industry does create employment, it cannot, however, absorb the high numbers of women who would need an alternative source of income if access to natural resources were restricted. Additionally, if the environment is degraded to the extent that villagers can no longer depend on it as their source of livelihood, the tourist industry will most probably move elsewhere, because it has destroyed the resource that attracted it in the first place. Consequently, villagers will be left with a degraded environment and no tourism.

Furthermore, women are constrained when it comes to employment opportunities within the tourist sector. The lack of language skills is an obvious obstacle. Time constraints and the risk involved are other explanations for women not entering the tourism market. Moreover, when discussing the opportunities for women within the sector one has to take into account the traditional relationship between men and women and remember that women operate within a cultural context based on gender division. This applies to both sectors, but especially to the informal sector activities. Women are more restricted to the private sphere and the informal sector is not as accessible for them. Now if women are to benefit more from this sector they have to move out of the private sphere and into the public sphere, which means more contact with the opposite sex. If this is not desirable one has to develop mechanisms where men sell in the public sphere what women produce in the private sphere.
When discussing further development of tourist projects one must also pay attention to the fact that the introduction of tourism in local communities also affects the traditions and social life of the host population. The tourists themselves can become a social burden in the sense of introducing new kinds of behaviour, and thereby challenging traditional codes of behaviour. In the context of Zanzibar, tourist activities such as drinking alcohol, dressing scantily and openly showing affection and sexual attraction are certainly at odds with Muslim culture. The introduction of new behaviour should not be underestimated. However, it has to be balanced with the rights of tourists to enjoy their vacations. Otherwise they will travel elsewhere.

The Zanzibar Government has widely recognised that the needs of local communities have to be balanced with those of tourism (Poulton, 1994; COLE, 1994), and there are official guidelines for tourist investments to secure these needs. There is also a Tourism Zoning Plan from 1993, which includes designation of areas having a potential for tourist development (COLE, 1993). Additionally, in order to prevent negative effects of tourism the government recognises that it is important that tourism is not only properly planned but also efficiently monitored (Mohammed and Issa, 1995).

However, women voiced the opinion that there should be a higher degree of local participation in tourism planning. More efficient information flows between local communities and tourism planners and implementers could solve some of the problems arising when it comes to access to resources. If investors or planners were aware of exactly how villagers used the resources and their area, conflicting interests between the two parties could be avoided. Another important aspect when it comes to information is to inform the local communities about the projects that are to be established in their surroundings. Bearing in mind that tourism might impose irreversible negative impacts on the livelihood of villagers, increased participation from villagers themselves is necessary to ensure that the benefits from tourism reach local communities, and secure their livelihoods.

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Dolphin tourism and community participation in Kizimkazi village, Zanzibar

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ABSTRACT

About 10 species of dolphins are found in the western Indian Ocean, of which only three—the bottlenose dolphin (*Tursiops truncatus*), the Indo-Pacific humpback dolphin (*Sousa chinensis*) and the spinner dolphin (*Stenella longirostris*)—have been observed in Zanzibar waters. The first two are commonly seen at Kizimkazi, which is the most popular site for dolphin tours. Marine mammals are increasingly valued by society for their intrinsic qualities rather than their harvestable economic worth and the villagers of Kizimkazi have started to realise this potential as well. Previously dolphins were used as bait for sharks. However, about 7 years ago the local fishermen realised that their touristic value far exceeded that of using them as bait. As many as 2000 tourists visit the dolphin site at Kizimkazi per month, for an average of US$ 20 per trip per boat and dolphin tourism is currently becoming an important economic activity. However, the community complains that they do not see its benefit as most of it goes to the urban area. Successful management of the dolphin tourism will ensure that tourists continue to visit the villages with dolphins and thus bring them income while contributing to management and conservation. This paper elaborates on the Kizimkazi village perspective on dolphin tourism and proposes ways in which to involve the community so that it is able to benefit from the activity and at the same time conserve the dolphins.

INTRODUCTION

Dolphins are the most common cetaceans inhabiting Tanzanian waters. There are about 32 species of oceanic dolphins worldwide (Jefferson et al., 1993). About 10 species are found in the western Indian Ocean (Guissamulo, 1997). In Tanzania only four of these have so far been observed through various studies and through personal observations. However, until now only three have been observed in Zanzibar waters. The bottlenose dolphin (*Tursiops truncatus*) and the Indo-Pacific humpback dolphin (*Sousa chinensis*) have been observed in Menai Bay, southwest of Unguja island (Stensland et al., 1998; Todesco, 1999) and the spinner dolphin (*Stenella longirostris*), together with bottlenose
dolphin in the north of Unguja island, along the villages of Nungwi and Matemwe (Ortland, 1997). It is also possible, though rare to see groups of 4–12 bottlenose dolphins in the vicinity of the harbour area in Zanzibar town (Jiddawi, pers. observ.). Along the coast of Tanzania mainland Chande et al. (1994) also observed three species—*Tursiops truncatus*, *Stenella longirostris* and *Steno bredanensis*—during a survey conducted along Mtwara, Dar es Salaam, Bagamoyo and Tanga. The Indo-Pacific humpback dolphin, *Sousa chinensis* is considered rare and possibly endangered throughout its range in the Indian and western Pacific oceans (Perrin, 1992).

Although dolphins seem to be fairly common in the waters around Tanzania, their biology, ecology and distribution is poorly understood. It is known however, that the bottlenose dolphin and Indo-Pacific humpback dolphin tend to prefer the coastal and inshore areas around Zanzibar (Depres, 1998; Stensland et al., 1998; Ortland, 1997), while spinner dolphins are usually found in slightly deeper water farther from the shore (Ortland, 1997). In Zanzibar, the Menai Bay appears to be the stronghold of the Zanzibar dolphin population (Stensland et al., 1998). Off Kizimkazi, bottlenose and Indo-Pacific humpback dolphins can be found throughout the year (Kizimkazi fishermen, pers. commun.). During daytime, they frequently come close to the shore to socialise, rest and feed (Amir, pers. observ.). Also the frequent sightings of calves around Menai Bay may indicate that the area is an important breeding ground for dolphins (Stensland et al., 1998).

The values which humans can derive from the marine mammals fall mainly into two categories: the consumptive ones in which the value derived is almost directly proportional to the number of animals killed, and the non-consumptive ones derived from animals living freely in their natural environment. There is also a category of low-consumptive values which involve taking of only a small number of animals for their realisation (UNEP, 1985).

Generally marine mammals are increasingly valued by society for their intrinsic qualities rather than their harvestable economic worth, as has been realised by the villagers of Kizimkazi (Jiddawi, 1998). Dolphins are naturally very sociable animals and it is because of this nature that many visitors pay considerable sums of money to watch their behaviour or even to play with them in their natural environment (Jiddawi, 1997). They are popular for their frequency of interaction with humans (Guissamulo and Cockcroft, 1997).

However, the well-being of marine mammals and sometimes their very survival are threatened by a variety of human activities. It is noteworthy that increasing fishing activity may cause a decline of mammal populations as a result both of the depletion of species on which the animals prey and the increase in their incidental, often unintentional killing, which occurs most often when the animals get entangled in nets and other fishing gear. It is also noteworthy that an important aspect of the problem arises from public interest in marine mammals, e.g. from dolphin watching. This is probably most significant where the populations are subjected to possible disturbance within their breeding grounds (UNEP, 1985).
Historically, bottlenose and Indo-Pacific humpback dolphins have lived with low boat traffic mainly fishing boats, for many years in the Menai Bay. Over the last seven years however, Kizimkazi has experienced an increase in boating activity both for fishing and tourism (Kizimkazi fishermen, pers. commun.) which is feared to create a negative impact on the dolphins.

This report briefly summaries the main findings of the survey on community perception on the dolphin tourism conducted at Kizimkazi-Mkunguni. The survey was conducted in April 1999 in order to determine the current status of the business, the prevalent problems and the possible management and conservation approaches that could be implemented by the villagers as well as promoting a community-based management system through a programme of research and extension.

Objectives
The objectives of this survey were:
- To determine the extent of knowledge on the dolphins and their uses;
- To identify aspects of the management and conservation of dolphins;
- To identify the extent of interaction between the dolphins with tourism and fisheries;
- To examine the prospects of dolphin tourism to the community; and
- To identify socioeconomic implications of dolphin tourism.

METHODS

Study site
The study was carried out in Mkunguni village, one of the two villages of Kizimkazi which is a small fishing village located on the southwest coast of Unguja island, about 40km from Zanzibar town (Figure 1). The other village is Dimbani. The two villages are about 3km apart. The estimated population of both villages for 1999 is about 2961, in which Mkunguni has 1779 and Dimbani 1182 people (Sheha, pers. commun.).

The vast majority of the men in Kizimkazi are fishermen, carrying out some of their fishing activities in Menai Bay (Figure 1). Hence fishing is the main source of livelihood for most households. Nowadays some of the fishermen, especially young men, are involved in the tourist industry as well. Thus besides fishing, they also take tourists to watch dolphins on a daily or seasonal basis. Most women and some men are involved in smallscale agriculture, with cassava, bananas, beans, pawpaws, yams, and sugarcane as the primary crops. A few of the women are engaged in rope-making and fishing along the intertidal area.

Data collection
Information was gathered through interviews, group discussions, observation and anecdotal sources. About 40 villagers (including the local head of village ('sheha') and his committee, hoteliers, teachers, fishermen and women, tour guides and boat operators) were interviewed at Mkunguni village. Data collected included: the occurrence and identity
Figure 1. Location of the two Kizimkazi villages and Menai Bay, in Zanzibar.
of dolphins in Menai Bay, the extent of dolphin fisheries and dolphin-tourism interactions and their impacts, historical background, information on the dolphin tourism management and conservation, a possibility of initiating sound management of dolphin tourism and how the community could achieve benefits from dolphin tourism.

RESULTS AND DISCUSSION

Dolphins identified by local fishermen and their uses
Fishermen mentioned three species of dolphins occurring in Kizimkazi water. The identification of species was verified through answers to questions on behaviour, body colour, size of individuals and group size. According to descriptions, there are black dolphins that are big in size (i.e. bottlenose) and white dolphins with a hump on their back (i.e. Indo-Pacific humpback). The fishermen also indicated the occurrence in distant offshore waters of Menai Bay, of huge groups of small dolphins which spin and jump a lot (which could possibly be spinner dolphins).

It is known that spinner dolphins tend to prefer offshore waters or slightly deeper waters farther from the shore (Koch, 1998; Ortland, 1997). It is also known that this species jump and spin and travel in groups of up to 200 or more individuals (Leatherwood and Reeves, 1983). The fishermen were not aware of the breeding periodicity or the dolphins life span. However, preliminary photo-identification analysis carried out in Menai Bay indicates that individuals are resident in this area, at least within one season (Stensland and Berggren, in prep.). In the Algoa Bay region of South Africa, mating and births occur throughout the year, but there is a peak of births in the summer months (Karczmarski and Cockcroft, 1997). Whether dolphins breed in Menai Bay or leave to breed elsewhere then return to feed and nurse their calves in this area needs investigation.

Uses of dolphins
The fishermen informed us that they were originally using dolphin meat as shark bait as well as food. They said that dolphin meat is preferred by most fishermen as shark bait due to its strong odour which attracts sharks from a distance. They also said that dolphin gut and blubber are used as waterproofing material (locally known as ‘sifa’) for boats. Hence dolphins were previously caught deliberately. For example, 23 dolphins were caught in 1996 by fishermen from Kizimkazi-Dimbani for use as shark bait (Abuu Kandimu, Kizimkazi-Mkunguni, pers. commun.). After realising the benefits from dolphin tourism they have stopped catching them. They also said that because dolphin meat contains a lot of blood, it is not preferred for food. Nowadays they use dolphins only as a tourist attraction.

History of dolphin tourism and its socioeconomic implications
According to Mr Abass Khalfan, a businessman who owns a guesthouse at Mkunguni and Mr Khamis Shaaban, a boat operator, tourism started in Kizimkazi in 1989 after the
trade liberalisation in 1987 by the Zanzibar Government. Tourists were taken out in outrigger canoes (‘ngalawa’) to snorkel on coastal reefs. Commercial tours to view and swim with dolphins however, began in 1992. The development of this activity led to the introduction of the motor boats that generated more money both in fishing and tourism especially at Mkunguni village. The increase in boats reached its peak in the last two years especially when the neighbouring village Dimbani joined in the trade.

More people, especially young men, joined the business, increasing the number of boats going to view dolphins. Some of these boats belong to the residents of the village and others belong to few residents of Zanzibar Town, who rent them to young men in Kizimkazi. There are now about 20 boats for dolphin tourism operating at Mkunguni and 15 boats at Dimbani. At Kizimkazi-Mkunguni about 10 boats are owned by villagers and 10 are owned by middlemen from the town.

Although the community is the basis of all activities, not all villagers benefit from dolphin tourism. They claimed that the benefits from dolphin tourism go to very few individuals, especially the tourist boat operators and few young men and women who provide services to the hotels. For example, in Mkunguni there are four restaurants and three hotels while Dimbani has only one restaurant but no hotels. That is to say, there is no economic benefit to the village as a whole.

Most women feel dissatisfied with their participation in dolphin tourism. They claimed that they do not realise any benefit from dolphin tourism at all. They said that their income has been tremendously reduced because they used to fish in the same areas where the dolphin boats now anchor or are now pathways for tourists going to view the dolphins, which has displaced them from using their traditional fishing spots.

Management and conservation aspects
The boat operators informed us that there are no management measures which control and regulate the activities of those involved in the dolphin tourism. For example, they said that there is no regulation which controls the number of boats around a pod of dolphins, no control of the boats over their movement and behaviour around dolphins and there is also no control on how to handle the boats or tourists once they have seen the dolphins. According to them, when the dolphin tourism expanded, they tried to initiate some management measures. However, those measures were informal and were done in collaboration with the local development committee under the leadership of local village leader (‘sheha’), but did not last long. Among the measures initiated were: fixing a common price and routine for all boats taking tourists to view dolphins and prohibiting the killing of dolphins in Kizimkazi waters for any purpose.

So far there is no provision in the Fisheries Act No. 8 of 1988 and Fisheries Regulations of 1990 to protect, conserve and manage the dolphins and regulate the dolphin-watching in Zanzibar in such a way as to prevent adverse effects on and interference with dolphins. Community-based ecotourism (such as dolphin tourism where the community benefits directly from tourists visiting an area and the money spent, rather than indirectly through a hotel, etc.), is one way of increasing the value of
natural resources to local communities. It may also prevent the exploitation of the resource by only one section of the community and could lead the Kizimkazi community, as a whole, finding the best possible solution of using this common property.

Impacts of tourism and fishing on dolphins
There is currently no evidence that the present level of disturbance causes stress on dolphins in the Menai Bay. However, the number of boats taking tourists to view dolphins is increasing and there is no legislative control. Considering the apparent importance of Menai Bay to the dolphins, the potential for increased disturbance, through an increase in tourism to the area, is cause for concern.

Dolphin watching is widely regarded as a sustainable non-consumptive alternative to the direct exploitation of cetaceans. However, uncontrolled dolphin watching could potentially threaten dolphin populations (Stensland et al., 1998). Meanwhile, dolphins that are forced to spend a great deal of time and energy avoiding boats may end up with reduced biological fitness as a consequence of the disruption of critical energy budgets.

Long-term effects of encounters of longer than 70 minutes a day may, for example, reduce breeding success, feeding activity and resting opportunity (Bejder and Dawson, 1998). If dolphin watching modifies dolphin movements or behaviour in ways that are biologically important, having boats accompany dolphins for such a high proportion of the time increases the risk of adverse effects such as dolphins leaving the area, avoiding boats or becoming aggressive towards swimmers (Barr and Slooten, 1998).

The fishermen claimed that fishing activities using nets do not cause any problem at all on dolphins. They said that in the last 5 years possibly only one or two dolphins have been caught accidentally and these were very tiny and could possibly have been calves. They believe that dolphins are intelligent animals and that they are able to see the net and escape away from it, which reduces by-catch of dolphins in their nets.

In a study conducted at Matemwe and Kizimkazi between 1995 and 1998 only two dolphins were observed landed at Mkokotoni fish market. Both individuals were small ones (less than a metre long) and from the colour they were identified possibly as bottlenose dolphin (Hamadi, pers. commun.; Jiddawi and Stanley, 1997). However, Chande et al. (1994) in a study conducted between January to November 1993, observed 19 incidental killings of dolphins in Dar es Salaam (2), Bagamoyo (4), Mtwara (5), and Tanga (8) and 14 intentional killings at Mtwara. Further investigation on this needs to be conducted to verify if the problem exists. Many fishermen are reluctant to address the issue, either by claiming that there is no by-catch or even to report accidental catches (Northridge, 1996).

Prospects for dolphin tourism
Tourism is an expanding industry in Zanzibar and most tourists pay a visit to Kizimkazi because of the presence of dolphins. In 1998 about 86,000 tourists paid a visit to Zanzibar. In the year 2000 over 100,000 tourists are expected to come to Zanzibar.
Hence, the presence of dolphins near Kizimkazi water offers opportunities for further development of dolphin tourism and could be a major source of income. Appropriate technologies that utilise locally available materials should be introduced in order to make the operations affordable and to promote dolphin tourism. This could create new employment opportunities, especially for women, which could improve the economic and social status of the community.

The people of Kizimkazi village also need training and capital for initiating small enterprises and for leasing boats and other equipment. Easy access to credit could encourage people to take part in dolphin tourism operations.

**Major constraints to the expansion of dolphin tourism**

*Lack of initial capital*

Most of the villagers do not have enough money to buy their own boats. For example, buying a boat to take tourists out is an extremely expensive process for fishermen in Kizimkazi, as one boat could cost up to TSh. 3 million (US$ 2500).

*Lack of community power*

Interviewees claimed that the community has less power to regulate access and use of resources in their areas for their social and economic development. For example, the income-generating scheme of collecting TSh. 500 per car entering the village for community development has assisted in building a dispensary and a fish market, bought medicine for their dispensary, supported local festivals, e.g. ‘maulid’ and supported school camps. The South District Commissioner for unknown reasons later stopped this scheme.

*Lack of technical know-how in tourism*

The lack of a tourism policy for Kizimkazi village leaves many issues pertinent to tourism vaguely addressed, such as scale of development, approach, and role of private sector. Consequently, things have been developing haphazardly with dire impact on dolphins. For example, boat operators claimed that nowadays they do not benefit from the dolphin tourism due to the reduction in the price charged. Initially the price was TSh 20,000 to 25,000 per boat, but it is now TSh. 10,000 to 12,000 or as little as 5,000, out of which they have to pay 15% revenue, 1.5% stamp duty, TSh. 1500 licence/year and TSh. 5000 for petrol.

*Lack of awareness*

There is in general a lack of awareness on dolphins of Zanzibar. Many people seem to be unaware that dolphins can be used as resources for the social and economic development of the community as a whole.
CONCLUSION

Dolphin tourism at Kizimkazi could be very successful. We are hopeful that with careful management it could be sustainable, and will have educational and conservation as well as social and economic benefits.

Economic opportunities in the villages of Kizimkazi are limited. Because of their poor economic situation, the people need more attention and help from both the government and non-governmental organisations. The utilisation of dolphins for dolphin tourism could mitigate the economic situation of Kizimkazi people and improve their economic status. A partnership between the local government and NGOs could accelerate the development of dolphin-tourism in Kizimkazi villages.

RECOMMENDATIONS

The following recommendations are made:

- To enact laws and regulations to govern the management and conservation of dolphins and provide a legal basis for the establishment of community-based management programmes.
- To incorporate within the legislation mechanisms for the community to share benefits from participation in management.
- To encourage public participation and community resource management to assist in law enforcement.
- To introduce regulations and rules that will govern dolphin watching and ensure that those regulations are followed.
- To conduct thorough studies on dolphin watching and fisheries activities and to identify means of reducing any adverse impacts that may be affecting the dolphin populations of Menai Bay.

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The Western Indian Ocean Marine Science Association (WIOMSA) is a non-governmental and non-profit organisation dedicated to promoting the educational, scientific and technological development of all aspects of marine sciences throughout the Western Indian Ocean region. WIOMSA provides a forum for communication and exchange of information, organises meetings and seminars on marine science findings and applications, supports marine research through the award of grants, and promotes and fosters inter-institutional linkage within and outside the region.

WIOMSA has established a Book Series that will cover relevant themes in marine science and its application. The Book Series focuses on the Western Indian Ocean region, but authors from outside the region who have conducted their research in the region are welcome to contribute. The editors of the Book Series solicit and publish thematic volumes and conference proceedings.

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