

**A socio-ecological assessment of fisheries in
three estuarine systems of the SW Indian Ocean –
identifying essential links for improved governance**

(Grant No: MASMA/OP/2016/1)

**Final Report
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1. Executive Summary

The Estuarize-WIO Project was originally funded by MASMA for the 2-year period between July 2016 and June 2018 and was thereafter extended to the end of 2019 without additional costs to MASMA. This final report was intentionally delayed, allowing for the publication of a Special Issue of the Western Indian Ocean Journal of Marine Science in December 2021, on research conducted during Estuarize-WIO. Estuarize-WIO was a regional project with partner institutes in South Africa, Mozambique, Tanzania, Kenya and Norway. It followed a transdisciplinary approach towards socio-ecological research in estuarine systems. The project relied on data from many sources, describing estuarine circulation and ecological functioning, changes in land use and land cover, small-scale fisheries, and a transition from rural to urban societies. Individual studies undertaken by Estuarize-WIO were mainly descriptive, feeding into a final phase of complex systems modelling, to assess recent (past 30 years) change in socio-ecological systems, brought by human population growth, economic development and climate change. A WIO-centric methodology, to mitigate logistic- and data limitations within a developing region in tropical latitudes, was tested and provided robust results. Estuarize-WIO achieved (and exceeded) most of its output objectives (datasets, numbers of graduates, peer-reviewed publications, conference presentations) but the outcome objectives (application of findings to improve governance of natural resource use; enhancing co-management) could not be achieved in the short time available. Limiting factors of the project were a short time frame (mitigated by an extension), too little expertise in social / socio-economic research in the team, equipment failure and inexperience in field work in some cases, and the effects of the COVID pandemic on international travel. Even so, the compiled datasets per estuary, adapted methodology, and the regionally collaborative approach are important legacies of Estuarize-WIO. The new knowledge and enhanced regional structures now provide a solid framework for follow-up projects to assess and respond to the threats of climate change in estuaries of the WIO.

2. Background

The Marine Science for Management (MASMA) programme of the Western Indian Ocean Marine Science Association (WIOMSA) invited full proposals for research funding in late 2015 for a 2-year project to be implemented between July 2016 and June 2018. The theme was “Conducting original and innovative research that contribute to improved understanding; leading towards the creation of enabling conditions for coastal and marine management; and leading to behavioural and social/environmental changes for sustainable development and improved human wellbeing.” A regional consortium of research institutes, coordinated by the Oceanographic Research Institute (ORI), submitted the Estuarize-WIO proposal (February 2016; Appendix 1) which was accepted for funding.

Following a review process the research grant (Grant No: MASMA/OP/2016/1) was awarded to the consortium. Partners were ORI (coordinating institute); Eduardo Mondlane University (EMU); Tanzania Fisheries Research Institute (TAFIRI); University of Dar es Salaam (UDS); Kenya Marine and Fisheries Research Institute (KMFRI); Technical University of Mombasa (TUM); and the Arctic University of Norway in Tromsø (UiT, Norway). The grant period was later extended from 2 years (2016-2018) to 3 years (2016-2019).

The project proposal for Estuarize-WIO (hereafter called Estuarize) was for a socio-ecological assessment of fisheries in three estuarine systems of the Western Indian Ocean (WIO), to identify essential links and feed-back loops for improved governance. The project was well-aligned with the MASMA theme, and the multi-national consortium fulfilled all the stated eligibility criteria. A key risk factor (restricted access to an area due to political instability) was mitigated in the project design, by covering 3 widely separated estuaries in the WIO (Bons Sinais Estuary in Mozambique, Ruvu Estuary in Tanzania, and Tana Estuary in Kenya) (Figure 1).

Transdisciplinary research included physical, hydrological and ecological aspects of estuarine functioning, household socio-economy, effects of urbanization, ecosystems goods and services (focusing on small-scale fisheries) and socio-ecological modelling. Existing data and limited field sampling were used to compile information bases per estuary. Analyses of trends covered a range of spatial (estuary zone to regional) and temporal (seasonal to decadal) scales. Research focussed on recent trends (past 30 years) to set a benchmark for future studies on the effects of climate change.

A comparison among estuaries indicated seasonal-to-decadal changes in estuarine socio-ecological systems in the WIO region, and that human-induced processes affected estuaries and dependent livelihoods more deeply than inherent physical differences. A WIO-centric methodology, to mitigate logistic- and data limitations within a developing region in tropical latitudes, was tested and provided robust results. The compiled datasets per estuary (see Santos et al., 2021 for a summary and accessibility information), adapted methodology, and the regionally collaborative approach are important legacies of the Estuarize project.

Estuarize generated a Special Issue of the Western Indian Ocean Journal of Marine Science (1/2021) with 9 peer-reviewed publications, and a peer-reviewed paper in the journal *BioInvasions Records* (Kuguru et al., 2019). Presentations at scientific symposia included 9 oral presentations at an Estuarize-WIO mini-symposium at the 11th WIOMSA Symposium in Mauritius in 2019, 1 poster and 2 oral presentations at the 10th WIOMSA Symposium in Dar es Salaam in 2017, and 1 poster at the 16th SAMSS Symposium in Port Elizabeth (South Africa) in 2017. Out of 6 Masters students supported by Estuarize, 4 have graduated.

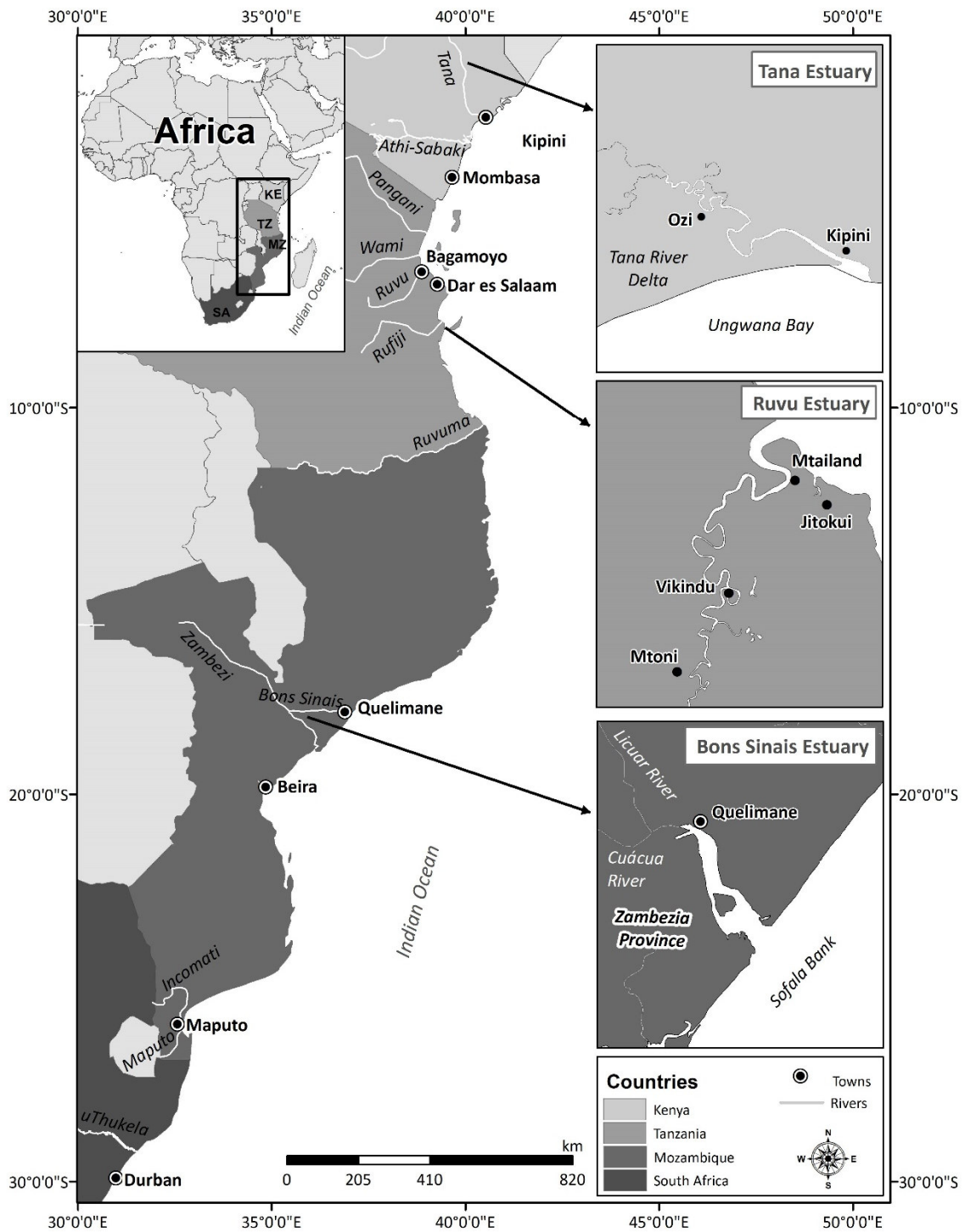


Figure 1: Estuarize-WIO project area in the Western Indian Ocean, with insets for the 3 estuaries studied: Tana Estuary in Kenya (top); Ruvu Estuary in Tanzania (middle) and Bons Sinais Estuary in Mozambique (bottom) (Source: Groeneveld et al., 2021a).

3. Project goals and objectives

Project goals (see Groeneveld et al. 2021a) were to:

- a. Describe and understand the estuarine biophysical environment, ecological function and natural capital, with a focus on seasonal and long-term change in land cover and land use;
- b. Define human user groups, socio-economic and cultural settings, and the reliance of livelihood activities on estuarine resources for food security and employment;
- c. Investigate small-scale fisheries as a key component of SES around WIO estuaries; and
- d. Identify essential links and feedback loops in SES that facilitate long-term sustainability of resource use and the conservation of critical habitats.

Additional goals were to develop decision-making tools that will allow for a better integration of resource use and management by public authorities; and to strengthen regional collaboration in the WIO among scientists and research institutes faced with similar challenges of resource assessment and provision of management advice.

Goals a-d were achieved and regional collaboration was strengthened significantly. Development of decision-making tools is a potential longer-term outcome, for which Estuarize has provided an information base and preliminary socio-ecological models (see Santos et al., 2021).

4. Project structure and implementation strategy

Project structure relied on 4 work packages (WP1 to WP4) by discipline (Figure 2), each led by an expert in that discipline. WP leaders ensured that projects undertaken at the three estuaries were aligned with project objectives and compatible. The data generated by WP1 – WP3 were used in independent descriptive studies per estuary, which then fed into WP4, a socio-ecological analysis to identify linkages and feed-back systems. A regional comparative approach was used to investigate trends at a larger latitudinal scale across the WIO region.

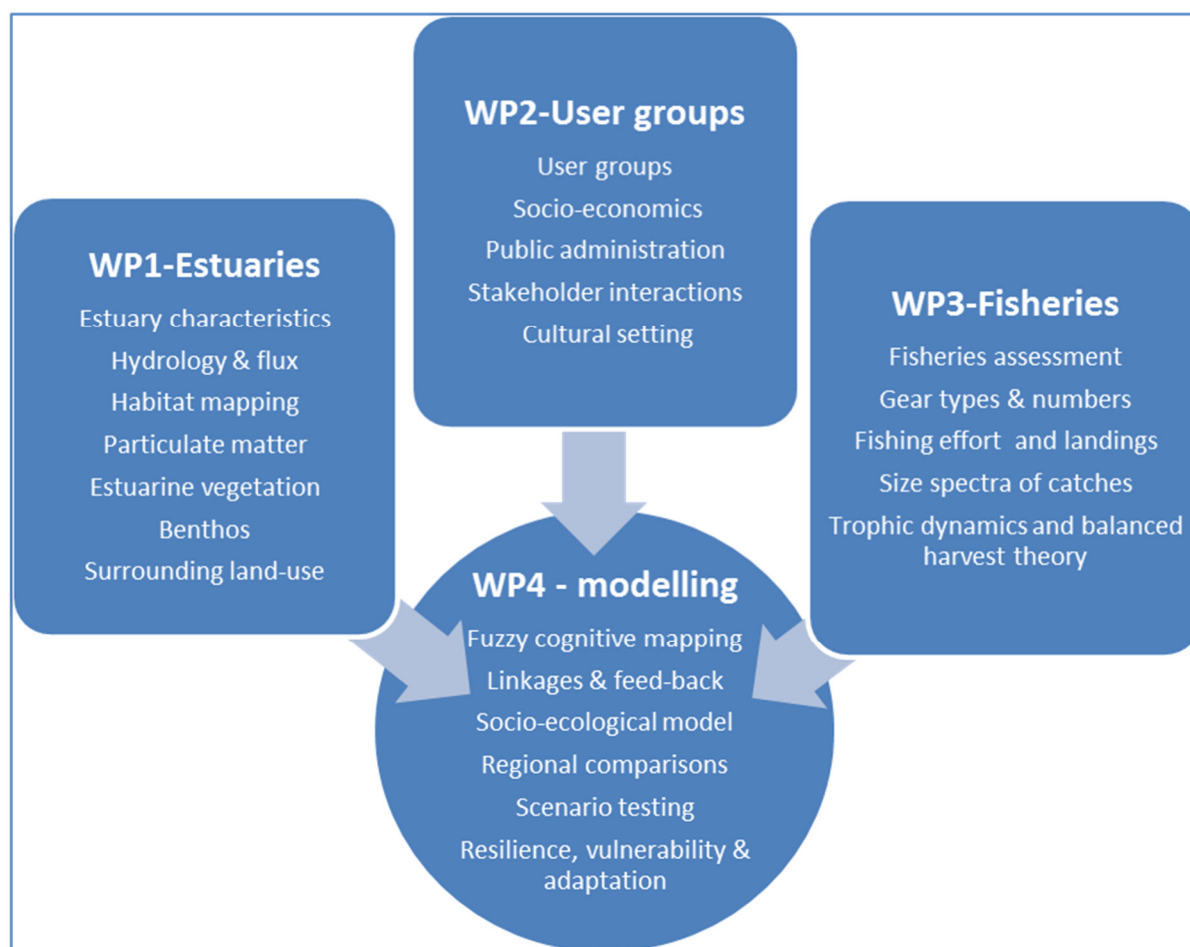


Figure 2: Relationships between Estuarize-WIO Work-Packages (WP) for different disciplines, feeding into a socio-ecological systems (SES) modelling framework (Source: Groeneveld et al., 2021a)

Research projects in WP1 – WP3 were implemented by the partner institutes in Mozambique, Tanzania and Kenya. In this decentralized way, each country retained responsibility and ownership of its projects and data, and funding could be disbursed equitably among partner institutes (Figure 3). WP4 was a cross-cutting package across disciplines and countries, using complex systems analysis in a regionally comparative analysis.

Regional workshops per WP took place in South Africa (ORI; implementation workshop; remote sensing workshop), Mozambique (EMU in Quelimane; estuarine hydrodynamics and year-1 progress workshop); Tanzania (UDS in Dar es Salaam; socio-economy and household survey workshop); and Kenya (KMFRI, fisheries workshop held at Diani). Additional workshops including partners from all

countries were held on an ad hoc basis (e.g., at the 10th WIOMSA Symposium in Dar es Salaam in 2017 and at the 11th WIOMSA Symposium in Mauritius in 2019).

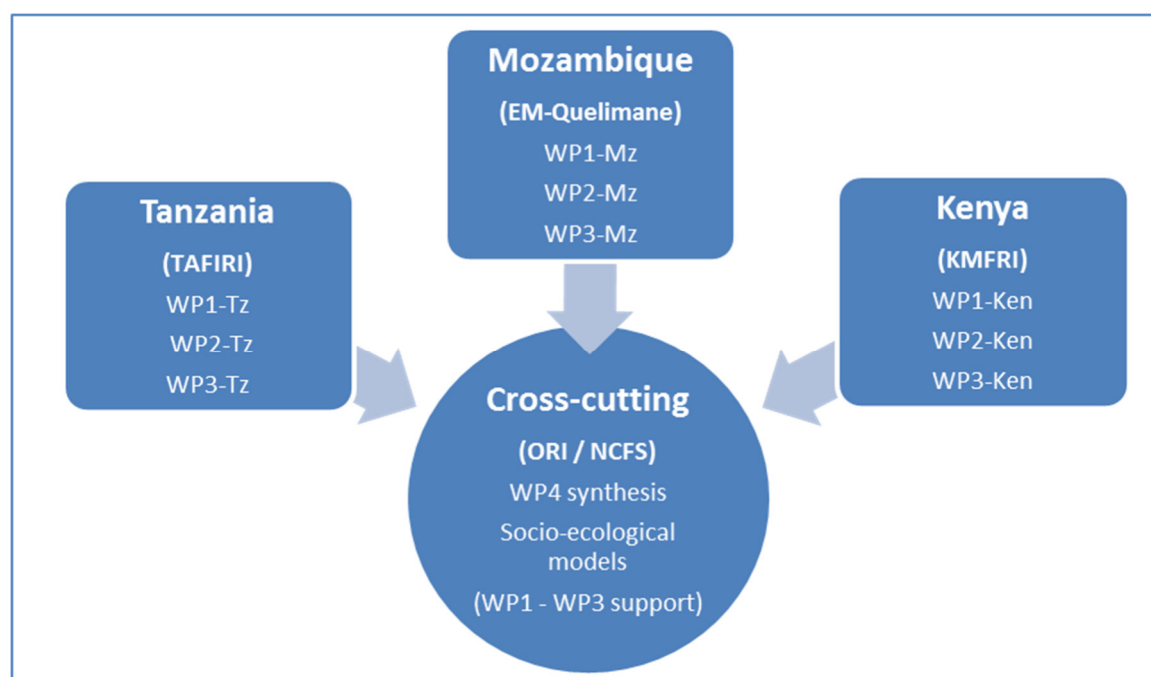


Figure 3: Decentralized implementation of Estuarize-WIO Work Packages (WP), with each country retaining the responsibility and ownership of national projects. On this basis, MASMA funding could be disbursed according to both regional and national workplans. WP4 was a cross-cutting package across countries and disciplines, using complex systems analysis in a regionally comparative analysis.

5. Representation and capacity development

Estuarize accommodated researchers from 5 countries (mostly Mozambique, Tanzania and Kenya) at levels of expertise ranging from professors to Masters degree students and technical support staff (Appendix 2). Both genders were represented at all levels of expertise. Leadership within the project was decentralized to country level. Regional leadership per Work Package was delegated to Mozambique (WP1), Tanzania (WP2), Kenya (WP3) and Norway (WP4). The project PI was from South Africa.

Six Masters degree projects (2 per country) were funded by Estuarize, with the grants covering university tuition, registration and a contribution to living expenses at local universities (i.e., EMU in Mozambique, UoS in Tanzania, and Pwani University in Kenya). Student projects were aligned with Estuarize objectives, thus contributing to the greater project. Project operating costs (i.e. consumables, equipment, infrastructure, field sampling costs) for students relied on the main project budget. Of the 6 Masters students, 4 have graduated with Masters degrees, and of them, 2 were first authors of publications based on Estuarize research (Manyenze et al., 2021; Mwamlavya et al., 2021).

6. Funding

Of a contracted ceiling of USD 165 000 (Appendix 3), MASMA disbursed a total of USD 164 321 to the project. Transfers were made directly to partner institutes (ORI in South Africa, EMU in Mozambique, University of Dar es Salaam in Tanzania, KMFRI in Kenya) based on annual Workplans generated at regional workshops held at ORI (2016) and EMU in Quelimane (2017). Disbursements per year and country are shown in Table 1. ORI contributed an additional USD 5000 to the project in 2019, mainly to fund accommodation for Estuarize participants at the 11th WIOMSA Symposium in Mauritius (presenters at an Estuarize mini-symposium as part of the main symposium), support an additional field trip to Tana Estuary, and for specialist GIS support (Appendix 3).

MASMA funding disbursed to ORI in South Africa were used for regional activities (regional workshops; specialist consultants; expenditure on Estuarize-WIO website; site visits by the PI) and to support partner organizations through disbursements for additional field work or shortfalls in funding for international travel and accommodation at workshops.

Table 1: Disbursements of MASMA funding (USD) per country			
	Year 1	Year 2	Total*
Mozambique	18021	29260	47281
Tanzania	19640	27500	47140
Kenya	19750	13900	33650
South Africa	28250	8000	36250
Total	85661	78660	164321
* Excludes USD 5000 contributed directly by ORI			

In-kind contributions to Estuarize-WIO included the use of long-term datasets collected by fisheries authorities and researchers in Mozambique, Tanzania and Kenya; use of institutional facilities for project administration (IT, administrative manpower and infrastructure); use of equipment for field sampling and data collection (vehicles, boats, CTDs); and scientific expertise (manhours to conduct projects, analyse data and write reports and publications). Although not measured consistently in terms of dollar value, there is no doubt that the in-kind contributions made by partner institutes and individual researchers combined exceeded the initial investment of MASMA in the project.

7. Project outputs

a. Peer-reviewed publications (10)

- Francisco RP, Hogue AM, Simbine RL, Mabota HS (2021) Household dependence on fish-based farming systems in the Bons Sinais Estuary in Mozambique. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 29-41
- Furaca NB, Hogue AM, MacKay F, Willemse M, Langa AA (2021) Exploring urbanization and critical habitat loss through land cover change around the Bons Sinais Estuary, Mozambique. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 43-58
- Groeneveld JC, Hogue AM, Kuguru B, MacKay F, Munga C, Santos J (2021a) Estuarize-WIO: A socio-ecological assessment of small-scale fisheries in estuaries of the Western Indian Ocean. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 1-15
- Groeneveld JC, MacKay F, Kuguru B, Mchomvu B (2021b) Socio-ecological change in the Ruvo Estuary in Tanzania, inferred from land-use and land-cover (LULC) analysis and estuarine fisheries. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 75-92
- Hogue AM, Gammelsrod T, Furaca NB, Cafermane AC, António MH (2021) The residual circulation profile of the Bons Sinais Estuary in central Mozambique - potential implications for larval dispersal and fisheries. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021:17-27
- Kuguru B, Groeneveld J, Singh S, Mchomvu B (2019) First record of giant freshwater prawn *Macrobrachium rosenbergii* (de Man, 1879) from small-scale fisheries in East Africa, confirmed with DNA barcoding. *BiolInvasions Records* 8(2): 379-391
- Manyenze F, Munga CN, Mwatete C, Mwamlayya H, Groeneveld JC (2021) Small-scale fisheries of the Tana Estuary in Kenya. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 93-114
- Mugabe ED, Madeira AN, Mabota HS, Nataniel AN, Santos J, Groeneveld JC (2021) Small-scale fisheries of the Bons Sinais Estuary in Mozambique with emphasis on utilization of unselective gear. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 59-74
- Mwamlayya HM, Munga CN, Fulanda BM, Omukoto JO, Thoya PZ, MacKay F, Manyenze FH, Groeneveld JC (2021) Natural resource-use in the Lower Tana River Delta based on household surveys and remote sensing of land cover and land use patterns. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 115-130
- Santos J, Groeneveld JC, MacKay F, Munga CN (2021) A regional assessment of seasonal-to-decadal changes in socio-ecological systems in the Western Indian Ocean. *Western Indian Ocean Journal of Marine Science*, Special Issue 1/2021: 131-162

b. Conference papers (11 oral and 2 poster)

- Furaca, N (2019) Change in estuarine associated land cover related to rapid urbanization of Quelimane town. Oral presentation. 11th WIOMSA Symposium, Mauritius

- Groeneveld J et al. (2017) A socio-ecological assessment of fisheries in three estuarine systems of the Western Indian Ocean – identifying essential links for improved governance. Poster presentation. 16th SAMSS Symposium, Port Elizabeth, South Africa
- Groeneveld JC (2019) Estuarize-WIO – using a socio-ecological systems (SES) approach to connect estuaries, livelihood strategies and small-scale fisheries, for better governance. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Hoguane AM, Gammelsrod T, Machaiaie HE, Tovela EH (2017) The combined thermal and salinity fronts and fisheries distribution pattern in a tropical shelf: the case study of Sofala Bank, Mozambique. Oral presentation. 10th WIOMSA Symposium, Dar es Salaam, Tanzania Oral presentation.
- Hoguane A, Santos J (2019) The residual circulation profile of the Bons Sinais Estuary in central Mozambique, with implications for larval dispersal and fisheries. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Kuguru B (2019) Invasive freshwater prawn *Macrobrachium rosenbergii* found in Rufiji and Ruvu River estuaries: Implications for small-scale fishers. Oral presentation. 11th WIOMSA Symposium, Mauritius
- MacKay F (2019) Land cover and land-use analyses using open-source satellite imagery and low-cost household surveys infers estuarine function for data-poor WIO estuaries. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Manyenze, F (2017) Characterization of Fisheries Resources in the Lower Tana Delta and Estuary, North Coast Kenya. Poster presentation. 10th WIOMSA Symposium, Dar es Salaam, Tanzania.
- Manyenze F (2019) Effects of gear, seasons and fishing locations on catch composition of small-scale fisheries in the Tana River estuary, north coast Kenya. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Munga C (2019) Comparison of small-scale fisheries and catch composition across four estuaries in the Western Indian Ocean region: effects of location, season, and gear type used. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Mwamlavya H (2017) Assessment of Socio-economic Factors Driving Fisheries Resource-use Patterns in the Tana River Delta Ecosystem, north coast Kenya. Oral presentation. 10th WIOMSA Symposium, Dar es Salaam, Tanzania.
- Mwamlavya H (2019) Natural resource-use in the lower Tana River delta, where rural livelihoods depend on functioning ecosystem benefits. Oral presentation. 11th WIOMSA Symposium, Mauritius
- Onyango P (2019) The problem with governing the use of unique natural resources in estuaries of the Western Indian Ocean coastal region. Oral presentation. 11th WIOMSA Symposium, Mauritius

c. Popular articles

- Groeneveld JC (2017) www.estuarize.org: New website brings estuaries and small-scale fisheries of the Western Indian Ocean to life. WIOMSA Newsbrief 22(1): 3. March 2017.

d. Website

www.estuarize.org

e. Masters theses

Cafermane, AC. Massas de água e circulação residual no estuário dos Bons Sinais [Translated: Water masses and residual circulation in the Bons Sinais Estuary]. School of Marine and Coastal Sciences, Eduardo Mondlane University, Quelimane, Mozambique

Mabota, HS. Valoração Contingente dos Ecossistemas do Estuário dos Bons Sinais pelas comunidades locais [Translated: Contingent Valuation of Bons Sinais Estuary Ecosystems by Local Communities]. School of Marine and Coastal Sciences, Eduardo Mondlane University, Quelimane, Mozambique

Mwamlavya HM (2019) Assessment of socio-economic factors driving fisheries resource-use patterns in the Lower Tana River Delta and estuarine ecosystem, North Coast Kenya. Pwani University, Kilifi, Kenya. 88 pp. <https://elibrary.pu.ac.ke/handle/123456789/271>

Manyenze, FH (2019) Characterisation of the fisheries resources of the Tana Delta ecosystem, north coast Kenya. 87 pp. Pwani University, Kilifi, Kenya

f. Datasets

The metadata of all datasets used during the Estuarize WIO project are shown in Appendix 4. Details are provided on 27 central datasets used for the project (Santos et al., 2021). Datasets are available online (Landsat and Sentinel satellite images) or can be accessed on request from the individual data owners at EMU, IIP, TAFIRI, KMFRI and ORI. Contact details of institutes and researchers responsible for the datasets are provided in the metadata in this report, and in Santos et al. (2021).

List of Appendices

Appendix 1: Estuarize-WIO Project proposal: A socio-ecological assessment of fisheries in three estuarine systems of the SW Indian Ocean – identifying essential links for improved governance

Appendix 2: List of partner institutes and individuals active in Estuarize-WIO between 2016 and 2019.

Appendix 3: Financial reconciliation for funds disbursed by MASMA to ORI

Appendix 4: Metadata of central dataset compiled and used during Estuarize-WIO, including newly collected field data, existing datasets collected by fisheries departments and other organizations, and open access maps based on satellite remote sensing.

Appendix 1

Estuarize-WIO Project proposal: A socio-ecological assessment of fisheries in three estuarine systems of the SW Indian Ocean – identifying essential links for improved governance

Title page

“A socio-ecological assessment of fisheries in three estuarine systems of the SW Indian Ocean – identifying essential links for improved governance”

“ESTUARIZE-WIO”

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Abstract

We propose a socio-ecological assessment of fisheries in three estuarine systems of the Western Indian Ocean (WIO), to identify essential links and feed-back loops for improved governance. The proposal is shared by a consortium of six institutes (five in the WIO region), with skills in estuarine ecology, socio-economics, fisheries assessments, spatial planning and quantitative modelling techniques. A broad latitudinal range in the WIO, and estuarine systems of different types and sizes, will be covered, i.e: Bons Sinais estuary at Quelimane in the Zambezia province of Mozambique; Rufiji delta in Tanzania, and the Tana River estuary in Ungwana Bay, Kenya. The project will rely on existing data and limited field sampling to compile a validated information base per estuary. Individual work packages will describe: (1) estuarine biophysical environment, ecological function and natural capital; (2) human user-groups, socio-economic and cultural setting; (3) fisheries and effects on trophic dynamics; and (4) socio-ecological modelling and regional comparison. A participatory approach and fuzzy cognitive mapping (FCM) techniques will be used to identify and quantify the essential linkages and feed-back loops in socio-ecological systems. Resilience, vulnerability and adaptation of socio-ecological systems to change brought about by climate variability, governance initiatives, or increasing societal demands will be assessed, using model simulations. Thus, the effects of different exploitation regimes, natural perturbations and governance strategies on livelihoods, ecological functioning, and fisheries can be predicted. The technique is a powerful management tool for use by governance bodies, to visualize the multiple linked consequences of management strategies. ESTUARIZE-WIO is well-aligned with the four thematic areas of the MASMA programme, and the multi-national consortium fulfils all the stated eligibility criteria. The proposal is for a 2-year project, and the key risk factor (restricted access to an area due to political instability) is mitigated in the project design, by covering 3 widely separated estuaries in the WIO. We believe that the proposal has high scientific merit, and that its results will lead to tangible outcomes for coastal communities, in terms of balancing short- and long-term socio-economic and livelihood goals with ecosystem health.

Background and rationale

Balancing ecosystem health with short- and long-term socio-economic and livelihood goals is a major challenge in the developing world, where change is often the only constant. In the context of the Western Indian Ocean (WIO), a balance between the 'human system' (e.g. communities, society, economy) and the 'natural system' (e.g. coastal and marine ecosystems) has supported subsistence livelihoods based on natural resource use over many centuries, with interactions relying on timely societal adaptations and natural biophysical resilience. These socio and ecological systems are explicitly linked in a two-way feedback relationship (Adger 2000, Redman et al. 2004, Berkes et al. 2014), which is often a self-reinforcing or self-moderating. McClanahan et al. (2009) followed a socio-ecological systems approach to identify linkages and feedback mechanisms in complex small-scale fisheries. They predicted that as the process matures, it will increase the inclusiveness of

resource management goals to include non-use factors, such as biodiversity and other ecosystem services – an advance over the somewhat disaggregated way in which social and ecological systems are usually investigated.

The recent 'Regional State of the Coast Report' (UNEP, 2015) shows that the demand for biological resources in the WIO region continues to increase, while the capacity of ecosystems to service these demands remain relatively constant, or decrease if they become degraded. Coastal livelihoods are threatened by an unprecedented increase in human population densities, modernization of exploitation methods, and climate variability. Capture fisheries, as a source of food security, employment and economic activity, is one of the most important areas of socio-ecological interaction (Ochiewo 2015), particularly in nearshore areas and in the vicinity of river mouths or estuaries, where productivity is high because of high nutrient inputs.

Key activities around estuaries in the WIO include fisheries, collections of shellfish in intertidal areas, harvesting of mangroves for building and fuel, small-scale aquaculture and subsistence agriculture, including herding and crop planting. Focussing on fisheries, key actors in socio-ecological systems are fishers, mainly men but also women and sometimes children who participate in collections of many fish and invertebrate species in the intertidal. Women also play a prominent role in the processing and marketing of fish (Jiddawi and Ohman 2002). About 18% of artisanal fishers in Mozambique are women (www.idppe.gov.mz - for Census 2012 results). Other occupations closely linked to capture fisheries are artisans that make and repair boats and fishing gear, middlemen that provide boats and gear to fishermen who do not have their own (Jiddawi and Ohman 2002) and traders who buy fish at markets and distribute it inland. Capture fisheries are also affected by seasonal fisher migrations, which have been described as a social adaptation to a complex environment (Fulanda et al. 2009; Wanyoni et al 2016). Governance of small-scale fisheries, sometimes through cooperative management initiatives, have been fraught with difficulties, for reasons such as the lack of alternatives to fishing, remoteness of some areas, and a lack of information on which to base workable governance systems. We therefore selected estuarine fisheries as a suitable model for investigating socio-ecological interactions, as an integrated system in which formal governance has had limited success.

Box 1: Balanced harvest strategy versus selective fishing

A balanced harvest strategy, in which living resources are exploited proportionately to their productivity, rather than through selection of larger species or sizes, proved to be an optimal fishing strategy in African lakes, provided that fishing effort (amount of boats, fishermen, gear) remained dynamic, pulsing in pace with resource availability (Garcia et al. 2012). The balanced harvest theory implies that all levels of the trophic pyramid should be exploited (from planktivores and benthivores at the base to top predators at the apex), so as to minimize fishing impacts on trophic balance of ecosystems. The wide variety of gears and methods used to exploit a broad spectrum of resources, species and sizes in the WIO, with seasonal variations, suggests that a de facto balanced harvest strategy may already exist in nearshore fisheries, and that it functions as a fundamental cog of the socio-ecological system. In the WIO region, consumers are willing to pay for small fish species, and balanced harvesting thus becomes an economically adequate solution while preserving the ecological web structure (Jacobsen et al. 2013). In contrast to selective fishing, a balanced harvest strategy is well suited to the Ecosystem Approach to Fishing (EAF); it may therefore be considered as a governance strategy to achieve ecological and social objectives in fisheries.

Our proposal is based on three separate estuarine systems covering a broad latitudinal range and three separate countries along the WIO coastline. We will use a generic methodology to describe the estuarine ecosystems and their variability (i.e. natural system), the socio-economic structure of the communities that depend on it (human system), small scale fisheries and other natural resource use (i.e. mangrove harvesting) and the interactions between the natural and human system. We will identify and quantify the essential linkages and feed-back loops in the socio-ecological systems, and model the effects of different scenarios (i.e. exploitation strategies; natural perturbations; governance strategies) on livelihoods and ecological functioning of the estuaries. It is a complex undertaking, in which we will rely mostly on existing long-term ecological and socio-economic information, with limited field sampling. We will use the participatory approach to access traditional / local knowledge, and to develop a consensual description of the community resources and issues of concern. The different perceptions will be formalized into representations that capture the dynamics and uncertainties about the future of the system, and its resilience to various exploitation strategies. We will also assess to what extent balanced harvest patterns are present in the region, and what the effects thereof on trophic webs are likely to be.

A well-structured and parameterized description of the socio-ecological systems will enable us to answer questions such as: what mechanisms exist to avoid destructive or wasteful practices such as discards? What alternative livelihood strategies are used? Are “balanced” ecosystems more productive and resilient? Do we find social innovations that can be transposed to other environments? What innovations and new employment opportunities can be found? Finally, how do governance paradigms align with the socio-ecological systems operative in the region, and how can governance be improved towards managing ecosystems (instead of individual fisheries) which will confer advantages measurable in ecological and economic terms?

Goals and objectives

- Develop a common understanding of estuarine ecology and biophysical variability of three estuarine systems typical of the WIO
- Identify natural resource use by communities that border on these estuaries, and the socio-ecological processes and feedback systems that have developed over time, with a focus on fisheries
- Develop decision-making tools that will allow for a better integration of resource use and management by public authorities
- Strengthen regional collaboration in the WIO among scientists and research institutes faced with similar challenges of resource assessment and provision of management advice.

Activities

- Use a generic methodology to describe the 3 estuaries, characteristic habitats and ecology in the context of biophysical variability (seasonal, interannual), and related to surrounding land use
- Use existing fisheries data and limited field samples to describe fisheries active in each estuary, based on gears used, fishing strategy, numbers of fishers and seasonal fluctuations, landings, species and size composition
- Assess whether fisheries are selective for specific species / size classes, or balanced across the trophic pyramid, and the likely ecological implications in each estuary (ecological modelling)
- Undertake stakeholder meetings to refine the understanding of resource use decisions, and construct cognitive maps of linkages and feedback mechanisms inherent in the socio-ecological systems
- Assess the resilience and adaptive capacity of the socio-ecological systems to social and environmental pressures that act over seasonal, yearly and longer term time scales, using models to test various scenarios.
- Compare the socio-ecological systems and their resilience over time at a regional level, using information from 3 estuaries located in Tanzania, Mozambique and Kenya
- Assess whether existing fisheries governance strategies are congruent with the socio-ecological systems in the 3 estuaries
- Develop a management tool (technique) that can be used to predict the effects of a change in governance strategies, societal flux or climate perturbations on socio-ecological systems.

Scope and compliance with thematic areas of MASMA

The MASMA Programme Committee requires that proposals should match the funds and 2-year time period available for the project. Therefore we rely mainly on existing data, with limited field sampling. Short term student projects are supported (i.e. projects for course-work Masters studies).

The proposal is aligned with the four thematic areas of the MASMA programme.

1. Vulnerability, Resilience & Adaptation

Socio-ecological linkages and feed-back systems in estuarine fisheries are described, and tested. We explore ecological resilience and vulnerability using empirical and modelling methods.

2. Coastal Livelihoods

The proposal centres around coastal livelihoods and their environments, and involves communities in a participatory manner. We cover a broad geographical scale, where contrast in socio-ecological systems is expected to occur

3. Governance for the Future

Predictive models to be developed for scenario-testing, as a governance tool which managers can use to evaluate the effects of their decisions on communities and also on the estuarine functioning and fisheries resources.

4. Cross-cutting

The approach is multidisciplinary, relying on estuarine ecology, social science, fisheries science, ecological modelling and governance. Information from these fields are synthesized in models to predict ecological and societal responses to policies. By focussing on 3 estuaries in different countries, we cover a broader range of possibilities, and contribute regionally, instead of locally.

Eligibility criteria

The Consortium fulfils the eligibility criteria in the following way:

- All principal investigators have PhDs or MSc degrees in relevant fields (i.e. fisheries research and modelling; estuarine ecology; social sciences and resource use), and are experienced practitioners in the WIO region (see Appendix)
- Four of the five consortium partners are from the WIO region: ORI (South Africa), Eduardo Mondlane University (Mozambique), TAFIRI and university of Dar es Salaam (Tanzania). The fifth partner is the Norwegian College of Fisheries Science (2 person months annually)
- The project leader is employed by ORI, South Africa. With one exception, the principal investigators (5 in total) are all scientists employed by institutes from the WIO.
- The project makes provision for MSc coursework students (short projects)

Methodologies

a) Strategic approach

The project will rely, as far as possible, on existing long-term data collected by partner research institutes and on remote sensing and satellite data obtainable from open internet sources (i.e. NOAA, NASA, SA Weather bureau). This strategy is expected to provide the bulk of information to describe the underlying variables affecting socio-ecological systems (i.e. precipitation; run-off; temperature; productivity; seasonality; land-use surrounding estuaries). We will rely on historical fishing effort and landings data to construct longer term trends. Where data are unavailable, or need to be augmented to fill specific gaps, field sampling will be undertaken. Short field trips to ground-truth existing data will be undertaken, as well as limited field sampling to ascertain gear selectivity, and species and size composition of landings. Field sampling will be undertaken by partner research institutes in each country to minimize costs of travel.

Three major planning meetings will be held (one in each country) – at the onset of the project (planning; budgets; goals; field sampling strategy and protocols, timeframe); a mid-term review when data will be assembled and progress reported; and a final wrap-up meeting to evaluate outcomes and the compile a final report. The strategic goals of the meetings are to strengthen regional links, harmonize activities, and ensure that similar protocols are followed.

We will use a participatory approach to refine the understanding of resource-use decisions, and to construct cognitive maps of linkages and feedback mechanisms inherent in socio-ecological systems. Local knowledge will be sampled through meetings with stakeholders, demonstrations and questionnaires.

The proposed strategic approach has several purposes, i.e:

- Covers a broad geographical scope in the WIO, and a range of scenarios
- Forms a framework for a regional project implemented at local level (i.e. individual estuary level)
- Provides a framework for integrating expert input with local / traditional knowledge
- Reduces costs of data collection by using existing information and limited field sampling
- Compiles and evaluates existing information as to its quality and quantity
- Allows for assessments at different levels, depending on the availability of data (long time-series longitudinal data v. cross-sectional and static data);
- Allows for socio-ecological modelling based on imprecise data obtained with quick appraisal methods, cross-sectional surveys, expert knowledge and interviews with stakeholders

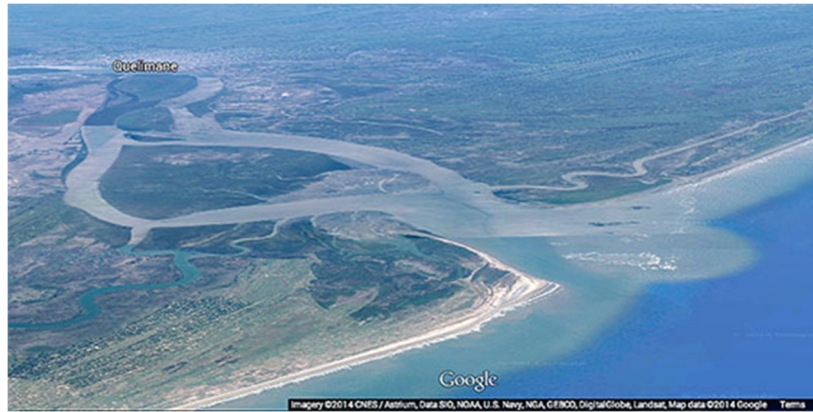
b) Sampling sites

We selected three estuaries for the proposal, one each in Tanzania, central Mozambique and Kenya, based on the following criteria:

- Artisanal / traditional fisheries present in the estuary
- Community reliant on fisheries located adjacent (or close to) the estuary
- Proximity of a research station (or fisheries office) as a collaborating entity
- Existing data describing fisheries / landings / size spectra available
- Information on socio-economic or cultural setting available, or easy to obtain
- Broad geographical coverage in the WIO (i.e. estuaries in different countries)

Apart from the above criteria, it was important that the selected estuaries should be 'typical' of the area in which they were located, so that the outcomes of the present study would be broadly applicable across the WIO region. We initially selected the Kosi Estuarine Lake system in eastern South Africa, but replaced it with the Tana River estuary in Ungwana Bay, Kenya, because of security concerns. Furthermore, the Ungwana Bay fisheries are more typical of the WIO than those at Kosi Bay. We also considered the Zambezi River delta, but preferred a smaller estuary in Mozambique, albeit in the same province.

i) Mozambique (Rio dos Bons Sinais)



The Rio dos Bons Sinais ("River of the Good Signs") was selected because of its importance to small-scale fisheries, availability of a considerable quantity of historical data, and the location of the UEM School of Marine and Coastal Sciences (consortium member) in Quelimane (capital of Zambezia province). The Bons Sinais originates at the confluence of the Cuacua and Licuar rivers (17°54' S; 36°49' E), and discharges into the Indian Ocean at 18°01' S; 36°58' E. The estuary is about 30 km long and 1.5 km wide, with an average depth of about 15 m. During intense flooding, it receives run-off from the Zambezi river, via the Cuacua - which occasionally re-establishes its historical upstream connection with the Zambezi.

The Bons Sinais estuary is linked to extensive freshwater wetland swamps and tidal creeks, and is fringed with dense mangrove forest, dominated by *Avicenna marina*. It is an important breeding and nursery ground for many commercial fish species. The artisanal fisheries census of Zambezia Province (2012) showed 32,368 registered fishers, and a total reported fisheries production of ca. 45 193 tonnes (2015). Of this, districts that border on the Bons Sinais estuary produced 7979 ton (about 18%). In 2015, 324 new artisanal fishing licenses were issued in Quelimane and Inhassuge districts – about 17% of new licenses issued in Zambezia.

Artisanal fishers operate in estuaries and in coastal waters using canoes and other small boats, and a variety of fishing gear including bottom trawls, beach seines, gillnets, hand-lines, traps, spears and mosquito nets. The catch is landed at artisanal fisheries centres along the estuary, and the product is sold on domestic markets. Historical data exists of fisheries landings (by species groups) and fishing effort (numbers of gear-type and days of fishing). Other significant livelihood activities along the estuary include agriculture (particularly maize and rice), mangrove harvesting for building materials and firewood, saltpans and aquaculture.

Major issues of concern in the Bons Sinais Estuary are the destruction of mangroves (as nursery and breeding ground for fishes), overfishing and use of destructive fishing gear such as mosquito nets.

ii) *Tanzania (Rufiji River delta)*



The Rufiji delta is part of Rufiji-Mafia-Kilwa (RUMAKI) seascape which lies on the central-southern coast of Tanzania. It experiences hot weather throughout the year, with a bimodal rainfall pattern of short rains in November-December and long rains in March-April. Average annual precipitation is 1000-1500 mm. The extensive Rufiji Delta, Mafia Island, Mafia Channel and the Songo Songo Archipelago dominate the seascape. The delta comprises of nine main channels, intersected with several smaller ones. These are dynamic, changing course as a result of annual flooding patterns. The ecosystem is rich in terrestrial, coastal and marine wildlife and plant resources, which form an important part of livelihoods of local communities (Turpie 2000; Tumbo et al. 2015).

The RUMAKI seascape covers about 9,000 km² with a total human population of about 200 000 people in 91 villages (67 villages are coastal) (NBS, 2012). The area includes the largest contiguous block of mangrove forest (Rufiji) in eastern Africa, and extensive coral reefs with high coral and fish biodiversity, important sea turtle nesting sites, and the only dugong refuge in Tanzania. Nutrient-rich water is provided by a constant year-round flow of the Rufiji River, which drains 20% of Tanzania land surface. The area sustains commercially important prawn, finfish and invertebrate fisheries, captured by multiple gear types. The delta contributes to the high fish productivity at Mafia Island, which supplies about 60% of fish found at fish markets, including in Dar es Salaam. Artisanal fishing is a key economic activity in the delta, where typical coastal households depend on fishing for 35-40% of their livelihoods. Dependence can however be as high as 80% of household income.

The major issues of concern in the Rufiji delta are over-exploitation of the fisheries resources (due to the use of dynamite fishery, use of small mesh size nets) and river discharge fluctuations, which affects availability of marine resources, such as prawns and fish. Migrant fishers occasionally increase fishing effort. Local communities have limited access to alternative livelihood means, which would reduce dependency on fisheries resources. Destruction of mangroves reduces nursery and breeding ground for fish, and also results in beach erosion. The extent of these effects need to be investigated.

iii) Kenya (Tana Estuarine System)



The Tana estuarine system is located at 40.5354°E, 2.5376°S. The Tana is the longest river in Kenya and the largest supplier of fresh water into Ungwana bay (Kitheka and Mavuti, 2016). The Tana River delta is the second most important estuarine and river delta ecosystem in Eastern Africa and was recently declared a Ramsar site and bird and biodiversity area. The system comprises of coastal habitats, including marine brackish and freshwater intertidal areas, and sandy beaches. The main channel meanders through 22 km² of mangroves, forming highly productive and functionally interconnected ecosystems (Kitheka et al., 2005). The ecological services offered by this area includes provision of nursery and feeding grounds to over 22 species of fresh water fish, feeding grounds for threatened dugongs and nesting grounds for turtles (BirdLife International, 2016).

The estuarine ecosystem plays a significant socio-economic role for communities living around it. Fishing, tourism and exploitation of the mangroves form the major economic activities (Samoilys et al., 2011). Fishing is the largest economic activity, including both artisanal fisheries and commercial trawlers. Fulanda et al. (2011) counted about 3500 artisanal fishers with a fleet of about 600 traditional boats and 3 semi-industrial shrimp trawlers operate in Ungwana Bay.

Major issues of concern in the Tana estuary are overfishing, poor land use and agricultural practices, mangrove overexploitation, overgrazing, interruption of water flow from upstream water supply, oil and gas drilling, destructive fishing methods and resource use conflicts (BirdLife International, 2016; Samoilys et al., 2011). Management of the bay has been a matter of concern for many years. For example, the trawl fishery was banned by the Government in 2006, as a result of user conflicts between trawl and artisanal fishers, and declining catches (Fulanda, 2003; Munga et al., 2012). The ban was lifted in 2011, with trawling restricted to beyond 3 nm from the shore.

The fisheries and biodiversity of Ungwana Bay have been extensively studied, including analysis of industrial prawn catches (1985-2010; Swaleh et al., 2015); artisanal and commercial fisheries (Fulanda et al., 2011; Munga et al., 2016); fisheries socio-economics (Odhiambo-Ochiewo et al., 2016); and biodiversity of ecosystems (BirdLife International, 2016; Samoilys et al., 2011). Nevertheless, a major shortcoming to date is an integrated study that links social, ecological and economic values to facilitate holistic management of the estuarine ecosystem.

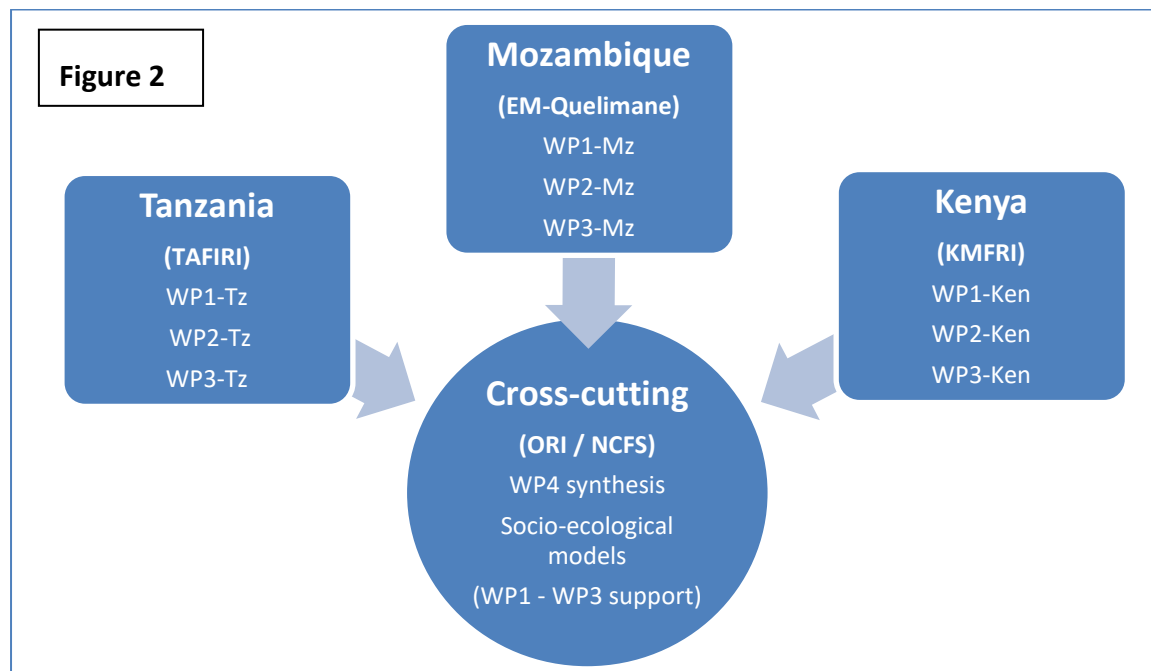
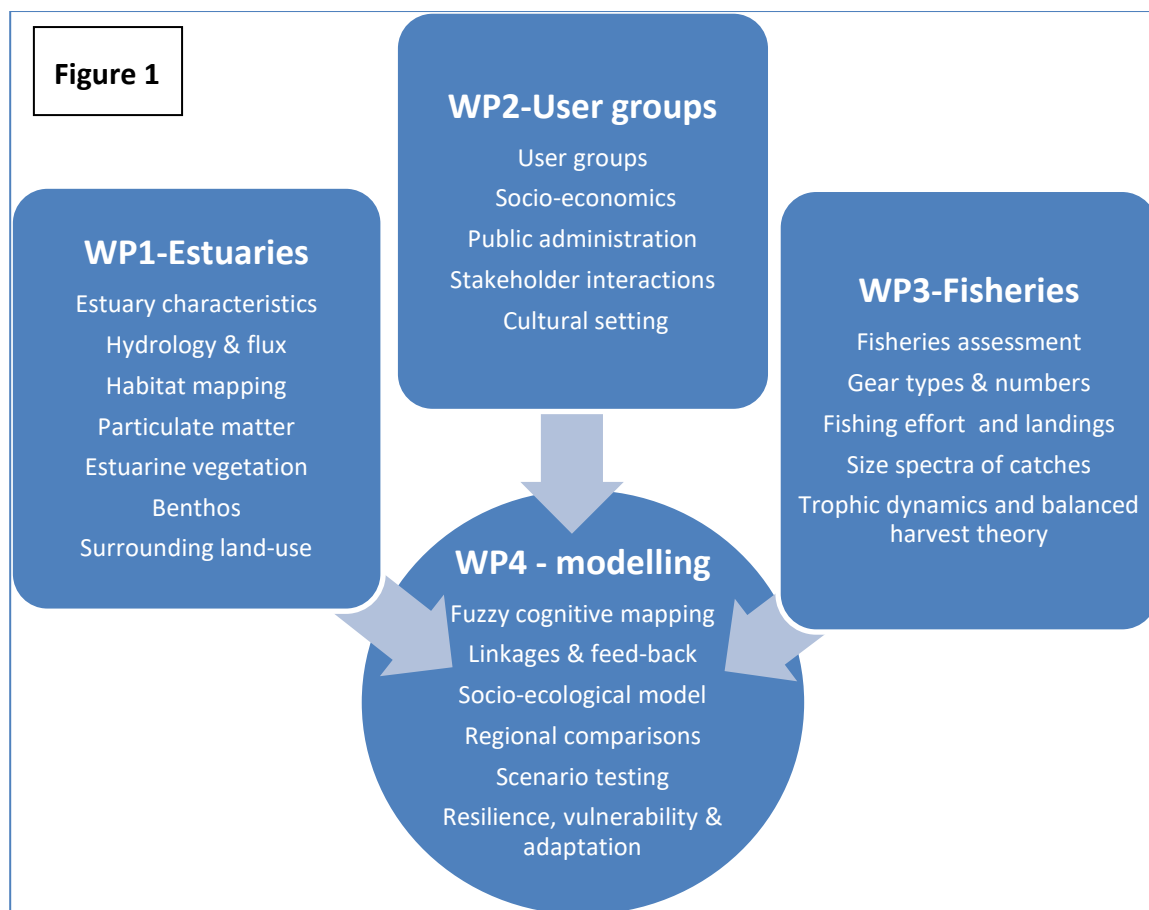
c) *Use of existing data*

Existing databases on which the study will rely will be sourced from Open Access sites on the internet (i.e. NASA, NOAA, SA Weather Bureau, SAEON). Spatial analysis of estuarine habitats and surrounding land-use using GIS (ARC GIS, IDRISI with module extensions for remote sensing) will be based on a combination of satellite imagery (Spot, Landsat, QuickBird, WorldView) and aerial photography (contemporary and historical). Fisheries monitoring data collected by fisheries departments and research institutes (TAFIRI, IIP, DAFF, DEA, ORI, Ezemvelo-KZN Wildlife) and frame survey data of fishing gears and effort (Fisheries departments) will be sourced, validated and summarised by project partners. Data on socio-economic circumstances (government statistics departments, IDPPE) will similarly be interrogated. Individual studies published in the peer-review literature and unpublished internal reports will be scrutinized, and historical data extracted for re-analysis within context.

d) *Project structure (Work Packages)*

The project will be structured into four work packages (WP1 to WP4) by discipline. Each WP will be led by an expert in that discipline (a Principal Investigator), who will ensure conformity of goals and methods used across the 3 countries per discipline. The information from WP1 – WP3 can stand on their own, as independent descriptive studies, but will also feed directly into WP4, where the socio-ecological analysis will take place to identify linkages and feed-back systems, and where scenario testing to assess resilience and vulnerability will take place (Fig. 1).

At an operational level, WP1 to WP3 will be implemented in each of the 3 countries, by the partner institute in that country. Thus each country will have its own coordinator, to guide the work to be done in WP1-WP3. In this way scientists in each country can participate in the full range of activities, under the guidance of a PI in each discipline, and supported by the country coordinator. WP4 will synthesize the information provided by the countries, and will be implemented as a cross-cutting package, across countries. Its technical workshops will be shared among countries, so that there are opportunities for scientists involved in the other WPs to participate in the modelling and synthesis of results (Fig. 2).



Implementation is therefore decentralized, but with oversight from a steering committee comprising of PIs that are experts in each of the disciplines in WP1-WP4.

The proposed Work Package leaders and the country or institutional leaders are as follows:

Project / Country level	Name & Institution
Project leader (Principal Investigator)	Johan Groeneveld (ORI)
Mozambique	Antonio Hogueane (UEM, Quelimane)
Tanzania	Baraka Kuguru (TAFIRI)
Kenya	Pascal Thoya (KMFRI)
Work package level (co-PI's)	Expert name & Institution
WP1 - Estuaries	Fiona Mackay (ORI)
WP2 - User Groups	Paul Onyango (UDS)
WP3 - Fisheries	Johan Groeneveld (ORI)
WP4 - Modelling	Jorge Santos (NCFS)

The details of the institutions and abbreviated CVs of the Principal Investigator and other senior project members are shown in Annex 1 and Annex 2.

e) Work Package 1: Estuarine biophysical environment, ecological function and natural capital

Approach

Estuaries are complex and variable, in part because of their inextricable link to their catchments. Thus, description of estuarine biophysical environment and estimation of ecological function in some part must include an evaluation of the attributes of the surrounding catchment. Within the constraints of budget and project timeframes, it is proposed that the biophysical characterisation of each estuary is at a rapid level of assessment that relies on existing data. Allowance will be made for at least one ground truth, field visit per site (low river flow condition to determine marine intrusion and nature of salinity gradient). Two field visits per system are preferable however, to evaluate the different physical conditions related to seasonal flow and rainfall.

The methods proposed will provide a descriptive setting for the variability of habitats (spatial analysis) and how these change with season (temporal analysis). The setting will provide a basis from which the overarching ecological function and provision of natural capital of each system can be presented.

Activities and Procedures

A four step procedure is proposed which includes a literature and metadata analysis at step 1 and an assessment of each catchment, including mapping of land-use at step 2. Individual estuaries will be considered in terms of current ecosystem function at various levels relative to pristine reference conditions at step 3. The final step presents the available natural capital of each estuary as system goods, services and attributes.

1. Data and Information Assessment:

This component relies heavily on existing knowledge from published and grey literature (including local community personal accounts). Individual estuary information and data will be categorised into: hydrology and hydrodynamics, bathymetry and sediments, water quality, microalgae,

macrophytes, invertebrates, fish, birds. Where data are poor, the likely attributes of individual components will be estimated through expert opinion. Continuous monitoring surveys (e.g. by water resource management authorities, indicator monitoring for biodiversity and resource evaluation) and individual static surveys such as for environmental assessments will be sought. Where possible, system physical information will be uploaded from existing gauging stations, continuous water level recorders and estuary mouth surveys.

Product: Literature/metadata review of the biophysical environment of three WIO estuaries.

2. Catchment typing and land use assessment:

Estuaries are classified according to inflow and mouth state. Catchment surface and groundwater capacities of catchments are important in this regard, specifically estimations of Mean Annual Runoff (MAR). Assessments of MAR (through seasonal flows) will set the lower catchment and estuary hydrodynamics for each estuary, in turn informing basic estuarine function. If MAR estimates are not available then basic rainfall-runoff models (e.g. De Kloe 2014) can be adopted. Here runoff replicas are developed using local knowledge, to calibrate individual catchment models which include annual precipitation patterns. MAR is required to evaluate the variability of estuarine inflow which is used to show seasonality of ecosystem function.

Land-use and land-use change analysis of individual estuaries will be conducted for each estuary, including surrounding terrestrial environment. This step will focus on spatial analysis of estuarine habitats and surrounding land-use using GIS (ARC GIS, IDRISI with module extensions for remote sensing) from a combination of satellite imagery (Spot, Landsat, QuickBird, WorldView) and aerial photography (contemporary and historical). Land-use change analysis will classify the surrounding landscape at four levels, including at least thirty evaluation categories, the top of this hierarchy being 'natural', 'transformed' or 'altered',

Product: Land-use and habitat maps and land-use change analysis for three WIO estuaries.

3. Estuarine typing and characterisation:

The fundamental nature of each estuary will be characterised relative to permanence of connectivity to the sea, salinity gradient, average bathymetry, hydrodynamics etc. Here field visits are necessary to validate habitat classification, land-use assessment and system hydraulics and hydrodynamics.

The sequential stages are:

- Estuary delineation to define and map upstream, downstream and lateral boundaries, including all areas below the high tide mark, all estuarine vegetation (e.g. mangroves, swamp forest, reeds/sedges and supratidal saltmarsh), and any floodplain areas to the 5 m topographical contour along each estuary bank
- Determination of estuary size (ha), including areas offshore in deltaic systems
- Determination of the present ecological status for all biotic components. This is an integrated assessment of all biophysical attributes, including a basic health assessment according to estuarine alteration (derived at step 2). The alteration scale ranges from natural to critically altered

- Estimation of the reference condition per estuary, to approximate alteration of original biophysical attributes, and the relative timeframes

The baseline and health assessment provides a description of the characteristics and functioning of all major abiotic (drivers) and biotic (response) aspects of the system and their relationships to one another, and the flow- and non-flow related pressures and impacts on the system. The proposed components are in part adopted from DWA (2011). Where limited data exist, the present state of the system may be limited to a narrative based on expert opinion. In this case the assessment will be reported with low confidence.

Product: Ecological status (driver and response variables) assessments of three WIO estuaries.

4. Evaluation of estuary natural capital:

This final step integrates products and data from the previous stages of assessment i.e. natural capital is elucidated from historical records, studies, proposed site visit and remotely captured image analysis. The system capital is grouped as follows:

Provisioning services (goods)

- Includes qualitative and quantitative descriptions of bait and other living resources used for recreational, subsistence and informal commercial purposes
- Raw materials (e.g. reeds and sedges for crafts, fencing and building, firewood, timber and poles from mangrove forests, building sand)

Regulating services (services)

- Description of nursery function, refuge and waste treatment and filtration capacity, output of sediments and nutrients contributing to marine production.

Cultural services (attributes)

- Estimation of trajectory of change (historical to forecasting) related to catchment activities and utilisation of the system

Product: Natural Capital assessment of three WIO estuaries.

f) Work Package 2: The human dimension - user-groups, socio-economic and cultural setting

Approach

WP2 will focus on the human dimension of the socio-ecological system and gather local information to develop the best achievable estuary management practices enabling sustainable exploitation of estuary resources. In particular the WP will examine (a) how socio-cultural and historical factors drive decision processes both at the level of individuals and in groups of actors at distinct levels (e.g. research community, local community, regional authority, national government, international trade) and (b) the pathways of resource use that arise out of these decisions. This analysis will elucidate social, economic and governance factors driving the decisions, and resulting in patterns of resource use. Furthermore it will contribute to the understanding of the ways in which local communities manage estuary resources also in relation to governance processes at higher levels. It is

hypothesized that local decisions on resource exploitation will be strongly influenced by economic opportunities. These decisions could lead to unbalanced exploitation pattern. It is therefore important to understand who the user-groups are and their linkages and reliance on the estuarine system for livelihoods, physical well-being and cultural expression. The WP will also examine the socio-cultural and socio-economic stressors to the estuary ecosystems health. It will explore the capacity and conditions for local institutions to take on governance functions and responsibilities, and what their shortcomings are. Land-use patterns relative to estuarine influences will be defined. An economic valuation of estuarine services to communities will be undertaken, taking account of seasonal effects on fish availability – the valuation will focus on provision services, such as fisheries, exploitation of mangroves for wood, aquaculture, transport and farming. Tourism and cultural services will also be considered (see proposed methodology below).

Methods

Economic valuation and interactive governance frameworks will be used.

Total economic valuation: Defined as an analytical framework that captures both market and non-market values associated with natural resource exploitation. Most research has focussed on market values, which are easier to capture than values of goods that are not traded in markets. Alternative methods to capture values considered important by communities are now receiving attention. We will conduct an analysis comparing values based on economic 'efficiency' principle (focused on market values) with those based on economic 'sufficiency' principle (important in resource-use decision-making, but difficult to capture). We will employ an 'environmental damage schedule' approach developed by Chuenpagdee et al. (2001), which has been applied in various coastal contexts around the world. The damage schedule approach is a non-monetary valuation method, using pairwise comparison to capture relative importance of natural resources. It is a simple and user-friendly method of eliciting values, judgment and preferences that can provide a starting point for discussion about trade-offs. A Masters student will undertake the economic evaluation.

Governability assessment framework: Governance to mitigate impacts of declining ecosystem services on coastal communities requires understanding of community characteristics and underlying value systems. Interactive governance offers a comprehensive framework to explore opportunities within natural and social systems (Kooiman et al. 2005; Chuenpagdee 2011). It rests on an understanding of the diversity, complexity and dynamics of these systems, and the recognition of scale issues that may influence effectiveness. The governability assessment examines system properties that are conducive or prohibitive, along with factors such as the responsiveness of the operating governance mode and the goodness-of-fit of chosen instruments (Chuenpagdee and Jentoft 2013). These considerations will be used to discern which governing interventions are appropriate in the context of the case study communities. A Masters student will undertake the governance research.

g) Work Package 3: Fisheries and effects on trophic dynamics

Approach and methods

The wide variety of gears and methods used to exploit a broad spectrum of resources, species and sizes in WIO estuarine fisheries suggests that a de facto balanced harvest strategy may already exist,

in which many levels of the trophic pyramid (from planktivores and benthivores at the base to top predators at the apex) are exploited proportionally to their productivity. WP3 will describe the fisheries in the 3 estuaries, using existing data on gears used, species groups and sizes caught. A broad approach to biological resource use will be taken, including mangrove harvesting, as these habitats play an important role as nursery or feeding areas for many fish and invertebrate species. Where fisheries data are not available, limited field sampling of landings will be performed. Seasonality of catches will be evaluated relative to high and low flow periods of the estuaries – thus sampling strategy will be structured accordingly. After constructing profiles of fishery removals from each estuary, quantifying total (all gears) removals by size category / species group, we will relate it to trophic dynamics of the estuary, determined from Ecopath models. We will then assess to what extent the overall exploitation pattern can be described as selective or balanced, by using models to simulate the effects of exploitation patterns (fisheries) on trophic dynamics of individual estuaries. A key question would be when trophic dynamics are under the least stress: when exploited mainly selectively, or mainly in a ‘balanced way? A comparison of the three estuaries will be undertaken to investigate variation across estuarine types, geographical and cultural ranges.

The outputs of WP3 will include a description of the fisheries in the three estuaries (effort, catches, species groups, size spectra) by season; trophic network representations by estuary; and an assessment of resilience / vulnerability of the ecosystems relative to the exploitation strategy (i.e. selective or balanced harvest). The information will feed into WP4, where the socio-ecological assessment (i.e. linkages between social and ecological systems and feed-back systems) will take place.

h) Work Package 4: Socio-ecological modelling and regional comparison

Approach and methods

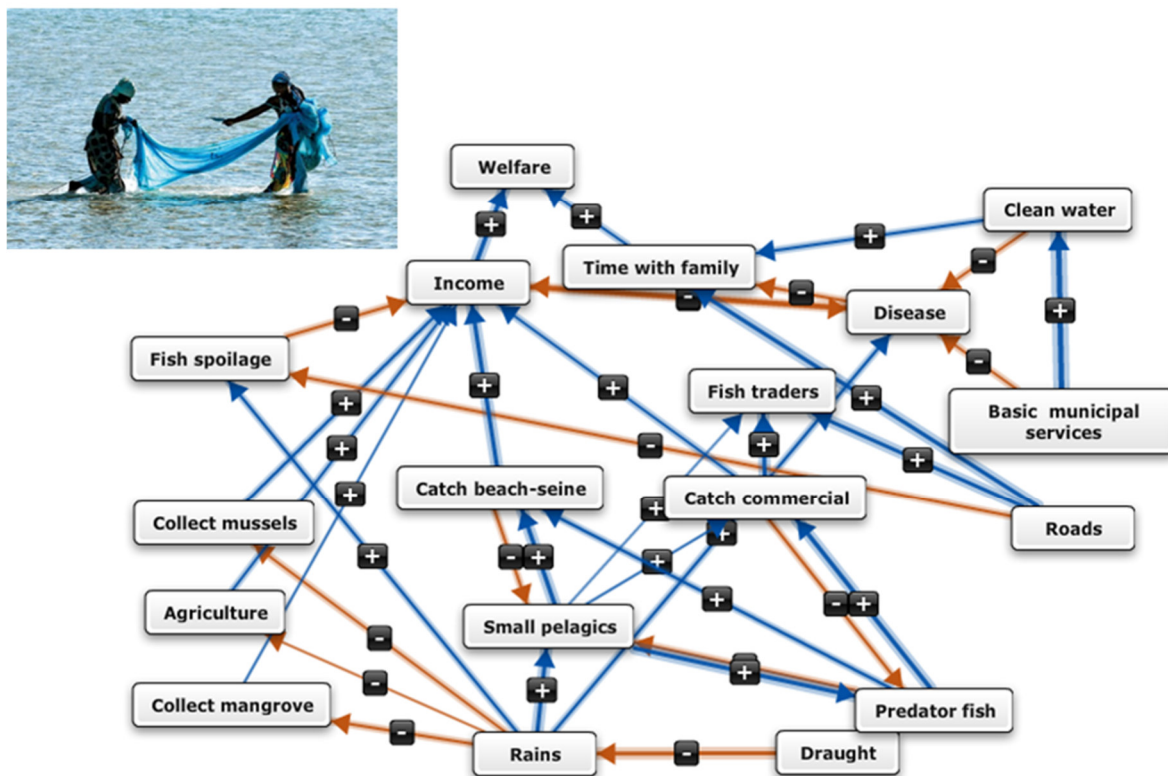
Planning and decision making will more likely succeed if the stakeholders in the communities and administration have a consensual description of the community resources and issues of concern. The different perceptions can be formalized into representations that capture the dynamics and uncertainties about the future of the system, and its resilience to various exploitation strategies. Therefore, we will attempt to represent the uncertainty in the system, interact with the stakeholders using a participatory research approach, and simulate the results of possible future actions or events using a parameterized form of concept mapping (Fuzzy Cognitive Mapping [FCM] approach). With FCM it is possible to develop qualitative static models that are translated into semi-quantitative dynamic models.

This planning and decision tool was originally developed as a way to structure expert knowledge (Kosko 1986). Several FCM software libraries to handle complex systems are available nowadays (Puheim et al. 2015), suitable for participatory research with both experts and communities. Examples of this participatory approach deal with facilitation of community disaster planning (Henly-Shepard et al. 2015), livelihood vulnerability in hunter-farmer communities in parts of the Great Limpopo Transfrontier Conservation Area (Murungweni 2011) or assessing the perception of vulnerability to climate change by coastal populations (Gray et al. 2014). Results of repeated participatory modeling interactions with stakeholders indicate that social learning occurs across individual and institutional levels, from short to long-term scales. Posteriorly to the analysis of

vulnerability and resilience, decision-making can rely on Analytic Network Process or Cost–Benefit Analyses, to assist governance bodies with decisions relying on different combinations of funding, manpower and organization.

Box 2: Fuzzy Cognitive Mapping (FCM)

FCMs are directed graphs capable of modelling interrelationships or causalities existing amongst concepts (nodes). Concept variables and causal relations constitute the two fundamental elements that FCMs employ for graphically describing systems. Concept variables are represented by nodes, Causal variables always depict concept variables at the origin of arrows; Effect variables, on the other hand, represent concept variables at the terminal points of arrows. An example of the utilization of FCM approach in the socio-ecological setting of women in a hypothetical fishing community in Mozambique is shown below.



This scenario focuses on the role of the women in the household and their intimate relationship with small-scale fisheries (often the beach-seining component). Also there are other interactions with the environment such as mussel collection, subsistence agriculture and collection of wood in mangroves, relative to other economic activities and society. The blue lines indicate positive relationships and the red lines indicate negative relationships, with arrows indicating directionality of the component influencing the other. Line thickness indicates the strength of relationships between variables, with thicker lines indicating stronger relationships. When the researcher / community agree on representation and strength of relationships, "what if" scenarios are run to determine how the system might react under a range of possible changes. For instance, in the example above, one could simulate the scenario of an effective ban on beach-seining, in isolation or in combination with for e.g. increased road building and/or fewer access rights to agriculture or aquaculture plots (the variable "agriculture"). The outcome from this scenario could be measured in terms of for e.g. potential susceptibility to disease, or income and time spent with the family. The last two variables

in this example were designed to contribute to the final receiver variable “welfare”. Few other techniques allow a strong simulation of complex systems such as this with equal simplicity and intuitive illustration. Complementary to this one, FCM analyses could be performed centered in other stakeholders (fishers, traders, district officers) or at higher levels (e.g. provincial administration, regional development projects, impact assessment by large industries).

WP4 also provides a basis to resolve key questions important to governance, such as: to what extent the present resource management regimes (in the individual estuaries) are effective, or congruent with an ecosystem-based exploitation pattern? Or whether the historical and present regime has given rise to social innovations that can be transposed to other environments?

Project activity plans

Project activities are structured by Work Package for ease of reference (see Table), but in many cases activities can be performed at the same time – for instance field sampling of estuaries can be combined with that of fisheries (i.e. WP1 and WP3); or participatory meetings with communities can be combined between the socio-economic and (WP2) and modelling (WP4) groups, saving time and costs.

Harmonization of activities within Work Packages and between them will take place at the initial implementation planning and budget meeting, at which a detailed project implementation plan will be developed, with specific goals and timeframes and budgets. All PIs will be invited to the meeting, as well as country coordinators and scientists (junior or senior) crucial to the implementation of the project. The Project Implementation Plan that emerges from the meeting will therefore be a shared product, to which partners have all contributed and can agree on. This includes products to be delivered and time-lines.

Two more management workshops are proposed –a mid-term progress meeting and a final wrap-up meeting for assessment and reporting. Smaller in-country workshops will be used to harmonize WP1-WP3 activities within each country. A WP4 modelling workshop to integrate data from WP1-WP3, and develop a management tool based on scenario testing will be held during the last quarter, shortly before the final wrap-up meeting.

WP1-WP4: Planning meetings and progress workshops
Implementation planning and budget meeting
Mid-term progress meeting (internal M & E)
WP4 modelling workshop to develop management tool
Final wrap-up meeting – assessments and report writing (internal M & E)
Country meetings to streamline activities in WP1-WP3 per country
WP 1: Estuarine biophysical environment, ecological function and natural capital
Data and Information Assessment
Catchment typing and land use assessment
Estuarine typing and characterisation
Evaluation of estuary natural capital
WP2: The human dimension - user-groups, socio-economic and cultural setting
Literature review and metadata analysis
Define user-groups and available livelihood options relative to estuarine ecosystem services
Trace historical pathways of resource exploitation and drivers such as trade, processing, local consumption and governance processes
Identify decision-making patterns for local estuarine resource users
Describe social and cultural make-up (incl. recent population growth and societal changes)
WP3: Fisheries and effects on trophic dynamics
Literature review and metadata analysis
Quantitative description of fisheries/gears by estuary, effort & landings based on existing data
Limited field sampling to refine species composition- and size spectrum data
Construct a profile of fisheries removals (all gears), accounting for season and year effects
Perform static and dynamic network analyses of ecosystem function and structure (ECOPATH)
Assess exploitation pattern relative to balanced / selective harvest theory
WP4: Socio-ecological modelling and regional comparison
Literature review and analysis of inputs from WP1-WP3
Participatory stakeholder meetings to develop cognitive maps of resource-use pathways, linkages and the process regulating resource-use decisions
Develop networks of relationships between natural and the social domains; for each estuary develop specific scenario models of local issues and configurations; test network scenarios using feedback analysis and fuzzy cognitive maps
Conduct analyses following 'what if' multiple scenarios of social and ecological change
Demonstrate / disseminate the technique as decision tool to managers / stakeholders

Activities will take place at three levels over the 24 month period of the project. The levels are the overall project level (strategic planning, M & E, guidance, responsibility for budgets and expenditure) the WP level (across countries, and led by an expert in each of the 4 disciplines) and country level (across work-packages within each country, led by the country coordinator). This multilevel mechanism was developed for the SWIOFP project (van der Elst et al. 2009) and was appropriate in a similar multilateral project involving many of the same partners.

A proposed time-frame over 24 months for the activities by level is shown in the Table below. Meetings will be held back-to-back where possible.

Month of project (out of 24)	Project management level	WP level (i.e. by Work package, WP1, WP2, WP3, WP4)	National level (i.e. by country and includes WP1-WP3 for that specific country , Tanzania, Mozambique, Kenya)
1-2	Implementation planning meeting (M&E) Website design and launch	Planning meetings (WP1-WP3)	3 planning meetings (Tz, Moz, Ken)
3-4		Protocols developed for existing data processing	Existing data collection, validation and processing
4-12		Literature reviews, data collection, data analysis WP1: GIS mapping, habitat distribution, seasonal dynamics, estuarine biophysical description, land-use maps WP2: User groups; livelihood options; decision processes and influences; governance WP3: Gears used, effort and landings by sp groups, seasonal / inter-annual trends; trophic network; balanced harvest? WP4: Participatory workshops, preliminary cognitive maps, networks developed	
13	Mid-term progress meeting (M&E)	Progress meeting	Progress meeting
6-18		Fieldwork planning and protocols, funding, equipment, permits	Fieldwork activities (sampling trips to ground-truth and collect new information. Continued participatory meetings. Two sampling trips per WP, one in low and another in high flow conditions)
14-20		New data processing and analysis & integration with existing datasets per WP1-3	
16-22		WP4 modelling workshop - cognitive mapping and simulations Synthesis of results across WPs and countries Development of management models	
21-24	Report-writing workshop	Report-writing (integrated by WP)	Report-writing (by country)
23-24	Final wrap-up meeting (M&E)	Models illustrated and recommendations for management	Models illustrated and recommendations for management
Post-project outputs	At least 4 publications in the international peer-reviewed literature are envisaged (1 per WP), although these will be written and submitted after the conclusion of the funding period. Scientific publications will be multi-authored to reflect the regional collaboration towards a specific aim.		

Outputs and outcomes

Multiple outputs are expected from this project because of its scope and multi-disciplinary nature. These are summarized in the Table below, to show their applicability in practice and potential impacts.

Outcome	Research Result/output	Potential users/beneficiaries of research?	How will the research benefit users?	What will be done to link research results to users?
Stronger networks and increased trust among researchers in the WIO. Enhanced platform for future shared projects	Agreed project framework & implementation strategy developed in a participatory way during planning workshops	WIO scientists and research institutes	Easier to collaborate regionally through networks of scientists	Workshops held in each country to bring together collaborators to participate in planning and implementation
Identification of data gaps for future attention on individual estuaries	Literature/metadata review of the biophysical environments, socio-economic circumstances and fisheries	Land-use planners, fisheries departments, governance bodies, researchers, policy makers	Provides a review of available information and gaps for future research.	Information disseminated broadly using electronic media, technical reports and peer-reviewed media.
Introduction of user-friendly cheap land-use change system that can be extrapolated to other estuaries	Land-use and habitat maps and land-use change analysis for three WIO estuaries	Land-use planners, governance	Better informed land-use planning along estuaries	Information disseminated broadly using electronic media, technical reports and peer-reviewed media.
Enhanced understanding of integrated individual biophysical components of estuaries that can be extrapolated to systems of similar size and type	Ecological status (driver and response variables) assessments of three WIO estuaries	Environmental and land-use planners, fisheries departments, governance bodies, researchers, policy makers, private sector, communities that depend on estuaries	Better understanding leads to more responsible user-behaviour, realistic management strategies, and improved environmental assessment of planned developments	Formal technical reports, peer-reviewed publications, dissemination through web portals
Enhanced understanding of estuarine user-groups, ecosystem services, livelihood options and decision-making processes of surrounding villages	Formal description of user-groups and their dependence on estuarine ecosystem services	Public sector administration, governance decision makers etc...	Better understanding will lead to more responsible user-behaviour, co-management strategies, support to local management units	Formal technical reports, peer-reviewed publications, dissemination through web portals
Better understanding of the impact of fisheries on estuarine resources, and ecological resilience to the exploitation strategies being used	Quantitative description of estuarine fisheries, including gear types, species caught and seasonal flux Assessment of fishery impacts on trophic dynamics, with focus on balanced / selective harvest theory	Fisheries departments, governance bodies, researchers, policy makers, private sector, communities that depend on fisheries	Better understanding and information base for decision-making	Formal technical reports, peer-reviewed publications, dissemination through web portals
Improved decision-making tools on which to base policy and management decisions	Cognitive maps exploring resource-use pathways, linkages and the process regulating resource-use decisions Graphic description of networks of relationships between natural and the social domains 'What if' descriptions of multiple scenarios of social and ecological change Decision tool (technique) that can predict direct and feed-back effects of decisions (or other perturbations) on ecological functioning and yields to resource users.	Communities dependent on estuarine services for livelihoods Public sector - governance of environmental, fisheries and social affairs Private sector - environmental NGOs, investors Communities dependent on estuarine services for livelihoods; public sector for governance; investors	Exploitation strategies based on best available information, used in an integrated way to predict outcomes of changes	Participatory approach, both through consensual decisions with stakeholders on effects of specific changes (direct through links and feed-backs) and through demonstrations of how the models can predict the result of specific actions. Formal technical reports, peer-review publications, web-based dissemination
Increased scientific and management capacity in the WIO	MSc Students trained; Decision making tool for predictions of outcomes	Communities & governance; Increased research capacity		
Enhanced platform for co-management initiatives	Decision making tool for predictions of outcomes; Participatory approach strengthened	Communities & governance		

Applicability of results in practice and potential impacts

See Output / Outcome table above. ESTUARIZE-WIO has high applicability in practice and potential impacts. It addresses socio-ecological systems that have proved to be resilient over time, but have now become vulnerable to the ever-increasing pace of change, both environmentally and in terms of increasing anthropogenic demands. Governance of these systems in the WIO have been patchy in the past, and plagued by a lack of information. It has also lacked the ability to integrate multiple factors into interlinked socio-economic and ecological function frameworks, which can then be used to predict the effects of changes brought by governance initiatives, societal flux or natural perturbations.

ESTUARIZE-WIO will focus on 3 estuarine systems, intensively mine the existing data describing the biophysical processes, surrounding human societies, and fisheries that support local food security and economies, and then assemble the information into models of socio-ecology that can be used to predict responses to change.

The likely outcome would be a far greater understanding of interaction and feed-back in socio-ecological systems around estuaries. Participatory work with stakeholders can assist communities and government agencies in understanding the implications of resource-use decisions at different levels. ESTUARIZE-WIO will produce a semi-quantitative cognitive mapping tool, to assist governance agencies and local communities to predict the effects of decisions or management strategies.

In this way, the decision-making process will be strengthened through its improved knowledge base and predictive capabilities.

Gender considerations

Gender is taken into account in this proposal at 2 levels. Firstly, the co-PI's and researchers in the project include several female scientists. *The co-PI of WP1 (Estuaries) will be Fiona Mackay (ORI) and in Mozambique, the researcher tasked with assessing the estuarine biophysical environment and ecological function of the Bons Sinais will be Juana Alberto Jose. We further undertake to support at least one (and preferably two) women students at the MSc level (see section on Students).*

Secondly, the project will deal to a large extent with fish processing and marketing, as a part of WP2, which deals with user-groups, socio-economics and cultural setting. Women are intricately involved in these processes, often in a leading role, and consequently much of the sampling, and project outputs will also focus on women.

Students

Provision has been made in the budget for one MSc student per country for Mozambique, Tanzania and Kenya. Given the relatively short lifespan of the project (2 years), coursework MSc projects will be preferred, in which a shorter fieldwork project will be aligned with the Estuarize-WIO objectives. The preferred gender ratio for MSc students will be 2 women to 1 male student. Both the University of Dar es Salaam in Tanzania and the Eduardo Mondlane University (School of Marine and Coastal Sciences) in Quelimane are consortium partners, and in Kenya, the project will rely on KMFRI to

recommend a suitable student. If this is not possible, the project will approach the Technical University of Mombasa (Dr Cosmas Munga) for assistance.

Importantly, the project partner from Kenya (Pascal Thoya, KMFRI) will use the project concepts, fieldwork opportunities and data as a platform for a PhD study. The PhD study is expected to extend beyond the lifetime of Estuarize-WIO. Training an expert in socio-ecological functioning of fisheries in estuaries is a good way to achieve an additional longer term impact in the region, beyond the project lifespan.

Monitoring and evaluation plan

The steering committee of ESTUARIZE-WIO will comprise of four members (the PIs that lead WP1 – WP4), and it will also have a Monitoring and Evaluation (M&E) function. The project will have three primary management meetings – one aspect of these will be to undertake M&E. The meetings will be as follows:

Implementation planning meeting (month 1 -2): Overall purpose to plan the project implementation with all partners present, and to set up detailed work plans with budgets and time frames (overall and for year 1 of the project). The M&E function of the meeting will be to set up an M&E schedule and terms of reference (ToR).

Mid-term progress meeting (month 13): Mid-term review to measure progress against the initial plans for year 1, and to proceed with more detailed planning and budgets for Year 2. All partners present. The M&E function would be to reviewed progress against the ToR, including work completed against initial activity plans and funding expenditure according to budget lines. The latter will be done with support of the finance department at SAAMBR. Formal report as output.

Final wrap-up meeting (month 23-24): Final reporting and an evaluation of overall performance, and performance per work-package. Funding and expenditure reporting will be overseen by the finance department at SAAMBR. SAAMBR is regularly audited and financial controls are therefore rigidly implemented.

Dissemination / communication plans

ESTUARIZE-WIO will use a multi-faceted communication / dissemination plan to reach a broad base of stakeholders. Electronic media will be used as far as possible – in this regard cell-phone technology has made great strides in the recent past, and many isolated areas also have access to internet. We will use these media to disseminate information and ‘advertise’ the project and its activities. An ESTUARIZE website will be designed and hosted as part of project management.

The Table below illustrates the levels, likely interest groups and preferred media that will be used.

Level	Interest groups	Media used
Internal	Project administration Project management Participating scientists Field workers	e-mail Telephonic Dropbox Website
Stakeholders around estuaries	Local user groups Resource users Community forums District administration Fisheries offices / field stations	Participatory meetings Demonstrations Information brochures Cell phone technology (WhatsApp) Website
Funders	MASMA/WIOMSA	Inception report Progress reports Final report Technical reports
Governance	Public administration Fisheries authorities Policy-makers RFMOs (SWIOFC)	Technical reports Policy recommendations Management recommendations
Other interest groups	NGO's Environmental interest groups Funding agencies General public	Website Information brochures Popular articles / lectures
Scientific community	Regional & international scientific community Students in the WIO	Scientific publications Presentations at symposia Technical reports

Risk analysis

Risk as a result of political instability or lack of access to sampling areas is mitigated by using 3 separate estuaries in different countries as sampling units. Instability in any one of the 3 areas can be addressed by shifting the focus and sampling effort to the other 2. The sampling methods are also fairly generic and can be applied to many different estuaries with artisanal fisheries in the region (i.e. in Madagascar or in Kenya). If needed, an estuary can be swapped for one in another country – although this may also require a change to Consortium membership. Overall, the Consortium partners consider the project to carry a moderate to low risk. The table below shows risks, their likelihood of occurrence (high; moderate; low), and suggested remedial actions.

Risk category	Likelihood of occurrence	Remedial action
Political instability prevents access	Moderate	Focus on other 2 estuaries or replace estuary with another (Kenya; Madagascar)
New data collection constrained by unfavourable sampling conditions	Moderate	Focus on analysis of existing data
Existing data of low quality or patchy	Moderate	Collect more new data Take into account in modelling by performing appropriate analyses. Level of analyses that can be attempted may differ between the 3 estuaries
Slow progress / below expected performance	Moderate	Identify at midterm progress review and implement remedial measures
Over-expenditure relative to funding	Low	Find additional research funds (PI's research funds or applying for bridging funding)

Matching funding plan

ESTUARIZE-WIO contributions will mainly be through scientific man-power, calculated as monthly salary costs plus administrative costs carried by the institutions that are part of the consortium.

Manpower	Unit cost (USD)	Units #	Unit description	Sum
(monthly salary+admin)				
Senior Scientist 1 (ORI)	3500	4	2months/y*2 yrs	14000
Senior Scientist 2 (ORI)	3000	4	2months/y*2 yrs	12000
Assoc Prof (Norway)	6500	4	2months/y*2 yrs	26000
Scientist (Moz)	3000	4	2months/y*2 yrs	12000
Scientist 1 (TAFIRI)	3000	4	2months/y*2 yrs	12000
Scientist 2 (UdS)	3000	4	2months/y*2 yrs	12000
Technical assistance	1000	12	6months/y*2 yrs	12000
				100000

Literature cited

- Adger, N. (2000) Social and ecological resilience: are they related? *Progress in Human Geography*, 24, 347-364.
- Bandeira, S. and Paula, J. eds., 2014. *The Maputo Bay Ecosystem*. WIOMSA.
- BirdLife International, 2016. Important Bird Areas factsheet: Tana River Delta.
- Chuenpagdee, R. (2011). Interactive governance for marine conservation: an illustration. *Bulletin of Marine Science*, 87(2), 197-211.
- Chuenpagdee, R. & Jentoft, S. (2013). Assessing governability – what’s next. In M. Bavinck, R. Chuenpagdee, S. Jentoft, & J. Kooiman, (eds). *Governability of Fisheries and Aquaculture: Theory and Applications* (pp. 335-349). Springer, Dordrecht.
- Chuenpagdee, R., Knetsch, J. L., & Brown, T. C. (2001). Environmental damage schedules: community judgments of importance and assessment of losses. *Land Economics*, 77(1), 1-11.
- Fulanda, B., 2003. Shrimp trawling in Ungwana Bay: a threat to fishery resources.
- Fulanda, B., Ohtomi, J., Mueni, E., Kimani, E., 2011. Fishery trends, resource-use and management system in the Ungwana Bay fishery Kenya. *Ocean Coast. Manag.* 54, 401–414.
- Fulanda, B., Munga, C., Ohtomi, J., Osore, M., Mugo, R., & Hossain, M. Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. *Ocean & Coastal Management*, 52(9), 459-466.
- Gray, S., Gagnon, A., Gray, S., Mahony, C., Muir, D., & Falaleeva, M., (2014). Are local coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping. *Ocean and Coastal Management* 94, 74-89.
- Henly-Shepard, S., Gray, S. A., & Cox, L. J., (2015). The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environmental Science & Policy* 45, 109-122.
- Jacobsen, N. S., Gislason, H., & Andersen, K. H. (2014). The consequences of balanced harvesting of fish communities. *Proceedings of the Royal Society of London B: Biological Sciences*, 281(1775), 20132701.
- Jiddawi, N. S., & Öhman, M. C. (2002). Marine fisheries in Tanzania. *Ambio: a journal of the Human Environment*, 31(7), 518-527.
- Kitheka, J.U., Mavuti, K.M., 2016. Tana Delta and Sabaki Estuaries of Kenya: Freshwater and Sediment Input, Upstream Threats and Management Challenges, in: *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean*. Springer, pp. 89–109.
- Kitheka, J.U., Obiero, M., Nthenge, P., 2005. River discharge, sediment transport and exchange in the Tana Estuary, Kenya. *Estuar. Coast. Shelf Sci.* 63, 455–468.
- Kooiman, J., Bavinck, M., Jentoft, S., & Pullin, R. (Eds.). (2005). *Fish for life: interactive governance for fisheries*. Amsterdam University Press MARE Publications, Amsterdam.
- Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J., Vanreusel, A., 2012. Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fish. Sci.* 78, 209–219.

- Munga, C.N., Kimani, E., Ruwa, R.K., Vanreusel, A., 2016. Species Composition of Fisheries Resources of the Tana and Sabaki Estuaries in the Malindi-Ungwana Bay, Kenya, in: *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean*. Springer, pp. 27–38.
- Murungweni, C., Van Wijk, M. T., Andersson, J. A., Smaling, E. M., & Giller, K. E., (2011). Application of fuzzy cognitive mapping in livelihood vulnerability analysis. *Ecology and Society*, 16(4), 8.
- NBS (2012). National Population and Housing Census of 2012. National Bureau of Statistics, Dar es Salaam.
- Ochiewo J., (2015). Social economic impacts of capture fisheries and mariculture. In J. Paula (Ed.). *The Regional State of the Coast Report: Western Indian Ocean* (pp. 306-315) UNEP-Nairobi Convention and WIOMSA, Nairobi, Kenya..
- Odhiambo-Ochiewo, J., Ruwa, R.K., Osore, M., Mutiso, D., Mwaguni, S., 2016. The Socioeconomic Causes and Impacts of Modification of Tana River Flow Regime, in: *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean*. Springer, pp. 131–139.
- Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F., (1998). Fishing down marine food webs. *Science*, 279(5352), 860-863.
- Puheim, M., Vascak, J., & Madarasz, L. (2015, January). A proposal for Multi-Purpose Fuzzy Cognitive Maps library for complex system modeling. In *Applied Machine Intelligence and Informatics (SAMII), 2015 IEEE 13th International Symposium on* (pp. 175-180). IEEE.
- Redman, C., Grove, M. J. and Kuby, L., (2004). Integrating Social Science into the Long Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change. *Ecosystems* 7(2), 161-171.
- Samoilys, M., Osuka, K., Maina, G.W., 2011. Review and assessment of biodiversity values and conservation priorities along the Tana Delta-Pate Island coast of northern Kenya. This Vol.
- Swaleh, K., Kaunda-Arara, B., Ruwa, R., Raburu, P., 2015. Ecosystem-based assessment of a prawn fishery in coastal Kenya using ecological indicators. *Ecol. Indic.* 50, 233–241.
- Turpie J.K.(2000).The Use and Value of Natural Resources of the Rufiji Floodplain and Delta, Tanzania Technical report No. 17, IUCN East Africa, Dar es Salaam, Tanzania.
- Tumbo, M., Kuguru, B.L., Igulu, M.M. 2015. Mid Term Evaluation Report on the Building Effective Long Term Fisheries Co-Management in Five Coastal Districts in Tanzania, and Promoting Coast-Wide Learning on the same Project, 2013 – 2017. WWF Tanzania Country Office, Dar es Salaam, Tanzania. x+72pp.
- Wanyonyi, I. N., Wamukota, A., Mesaki, S., Guissamulo, A. T., & Ochiewo, J., (2016). Artisanal fisher migration patterns in coastal East Africa. *Ocean & Coastal Management* 119, 93-108.
- Zhou, S., Smith, A. D., Punt, A. E., Richardson, A. J., Gibbs, M., Fulton, E. A., Pascoe, S., Bulman, C., Bayliss, P., & Sainsbury, K., (2010). Ecosystem-based fisheries management requires a change to the selective fishing philosophy. *Proceedings of the National Academy of Sciences* 107(21), 9485-9489.

Appendix 2

List of partner institutes and individuals active in Estuarize-WIO between 2016 and 2019.

Appendix 2: List of partner institutes and individuals active in Estuarize-WIO between 2016 and 2019

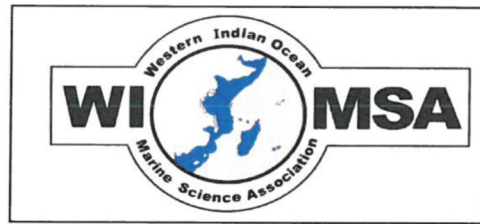
Acronyms: EMU = Eduardo Mondlane University; IIP = Mozambique Fisheries Research Institute; UDS = University of Dar es Salaam; TAFIRI = Tanzania Fisheries Research Institute; NMI = Nelson Mandela Institute for African Science and Technology; KMFRI = Kenya Marine Fisheries Research Institute; TUM = Technical University of Mombasa; PU = Pwani University in Kilifi; ORI = Oceanographic Research Institute; UiT - The Arctic University of Norway in Tromsø

Country	Institute	Name	Gender	Level	Role in project
Mozambique	EMU	Antonia Hogueane	M	Expert (Prof)	Project leader Moz; Regional WP1 leader (hydro)
Mozambique	EMU	Eulalia Mugabe	F	Expert	WP3 (Moz)
Mozambique	EMU	Rodrigues Pita Francisco	M	Expert	WP2 (Moz)
Mozambique	EMU	Noca Furaca	M	Expert	WP1 (Moz)
Mozambique	EMU	Anabela Cafermane	F	Masters student	Masters project in WP1 (graduated)
Mozambique	IIP	Humberto Mabota	M	Masters student	Masters project in WP2 (graduated)
Tanzania	UDS	Paul Onyango	M	Expert (Prof)	Project leader Tan (shared); Regional WP2 leader
Tanzania	TAFIRI	Baraka Kuguru	M	Expert	Project leader Tan (shared); WP3 (Tan)
Tanzania	UDS/TAFIRI	Boniventure Mchomvu	M	Technical	Support in WP1-WP3
Tanzania	NMI	Masumbuko Semba	M	Expert	WP1 (Tan); GIS support
Tanzania	UDS	Ansila Kweka	F	Masters student	Not completed
Tanzania	UDS	Humphrey Sanga	M	Masters student	Not completed
Kenya	KMFRI	Pascal Thoya	M	Expert	Project leader Ken (shared); WP1 (Ken)
Kenya	KMFRI	Johnstone Omukoto	M	Expert	Project leader Ken (shared); WP2 (Ken)
Kenya	TUM	Cosmas Munga	M	Expert (Prof)	Regional WP3 leader
Kenya	PU	Hamadi Mwamlavya	M	Masters student	Masters project in WP1 and WP2 (graduated)
Kenya	PU	Fatma Manyenze	F	Masters student	Masters project in WP3 (graduated)
South Africa	ORI	Johan Groeneveld	M	Expert (Prof)	Principal Investigator
South Africa	ORI	Fiona MacKay	F	Expert	Regional WP1 leader (LULC)
South Africa	ORI	Marinel Willemse	F	Technical	WP1 GIS and Remote sensing support
South Africa	ORI	Natasha Rambaran	F	Administration	Project administration
Norway	UiT	Jorge Santos	M	Expert (Prof)	Co-Principal Investigator; Regional WP4 leader

Appendix 3

a) Original Contract between WIOMSA and Grantee

b) Financial reconciliation for funds disbursed by MASMA to ORI



CONTRACT BETWEEN WIOMSA AND GRANTEE¹

Grant No: MASMA/OP/2016/01

ARTICLE I. TERMS OF AGREEMENT

- 1.1 This contract (hereinafter, together with the annexes attached hereto, called "the Contract") is made and entered into by and between the Western Indian Ocean Marine Sciences Association, (hereinafter called "WIOMSA") and the Grantee (hereinafter called the "Grantee").
- 1.2 This research Grant is awarded to **Oceanographic Research Institute (ORI); Tanzania Fisheries Research Institute (TAFIRI); School of Marine and Coastal Sciences, Eduardo Mondlane University; Department of Aquatic Sciences and Fisheries, University of Dar es Salaam and Kenya Marine and Fisheries Research Institute (KMFRI)** (collectively known as the "Grantees") to undertake a research Project entitled **"A socio-ecological assessment of fisheries in three estuarine systems of the SW Indian Ocean – identifying essential links for improved governance (ESTUARIZE-WIO)"** details of which are contained in the attached approved proposal.
- 1.3 The duration of the project shall be for **28 months**
Starting Date: **1 July 2016** Ending Date: **30 June 2018**
- 1.4 The WIOMSA undertakes to provide funding for the proposed project for the total amount of **US \$ 140 000**. This grant is shared between Oceanographic Research Institute (ORI); Tanzania Fisheries Research Institute (TAFIRI); School of Marine and Coastal Sciences, Eduardo Mondlane University; Department of Aquatic Sciences and Fisheries, University of Dar es Salaam and Kenya Marine and Fisheries Research Institute (KMFRI), as per the approved budget.
- 1.5 Reporting Procedures:
- 1.5.1 The Grantee will submit to WIOMSA annual progress reports and financial statements prepared according to the agreed format.
- 1.5.2 The Grantee will submit to WIOMSA Final technical and detailed financial reports prepared according to agreed format.

¹ Grantee will be an institution

1.5.3 The Grantees will attend “*Annual Meetings of the Marine Science for Management (MASMA) Grantees*” organized to evaluate the performance of approved projects based on the scientific results achieved.

1.6 Utilisation of Funds:

1.6.1 Each Grantee are responsible for their own accounting. The funding will be paid into the account(s) specified by each of the grantees.

1.6.2 The Grantee shall keep accurate and systematic records and accounts in respect of services rendered in pursuant of this Contract which clearly identify all charges and expenses of the project. All expenditures of the project should be accompanied by written evidence.

1.6.3 Major reallocation in project budget (+ or - 15% on each budget item) shall be agreed upon, in advance, in writing between the parties and with explicit reference to this clause in the contract.

1.6.4 If after meeting the costs of the project, there are unexpended funds under this contract the Grantee shall return such unexpended funds to WIOMSA.

1.6.5 In the event of the Grantee's non-compliance or partial compliance with the terms of this Contract, he/she shall refund to WIOMSA any payment already received in respect to activities that have not been performed by the Grantee to a standard considered acceptable to WIOMSA.

1.7 Payment provisions: [Payment schedules can be changed by written agreement between both parties]

1.7.1 Disbursement of grants shall only be made against separate Requisition for funds signed by grantees. The Requisition shall show:

- ❖ The grant number
- ❖ The name of the project
- ❖ The name of the grantee making the application and his/her address
- ❖ The persons who are the authorised signatories for the project account and their functions in the host institutions
- ❖ The requisitioned amount in US\$
- ❖ The project's bank account, bank address, account number, account holder, and currency of the account

1.7.2 An initial payment of **US\$ 70 000** shall be available for disbursement upon signature of the contract and requests for payment by the grantees;

1.7.3 Second and subsequent payment of the grant will be disbursed to cover every year following acceptance by the Programme Committee of the progress report of the preceding year and financial statement supported by duly receipted expenditure and requests for payments by grantees;

1.7.4 Payment of the final year will be reduced by 10% which amount will be disbursed upon receipt and approval by the Program Committee of a final technical report and a detailed financial report (accompanied by duly receipted expenditures).



ARTICLE II: CONTRACTUAL CONDITIONS

The general conditions applicable to WIOMSA Grantees are attached to this contract as Annex I and form an integral part of it.

ARTICLE III: LIABILITY

WIOMSA assumes no responsibility in the event of sickness, accident, death or disability of the Grantee nor does it arrange for insurance of the Grantee or reimburse premiums paid thereof.

ARTICLE IV: AMENDMENTS

Any amendments to this Contract shall be effected only on the basis of written mutual consent by the parties.

ARTICLE V: CORRESPONDENCE

All correspondence in connection with this contract shall be addressed to the WIOMSA Secretariat.

ARTICLE VI: ACCEPTANCE

To acknowledge acceptance of the terms and conditions of this contract, including terms and conditions of the annex attached hereto, sign **both** originals in the space below and return **one** signed original to WIOMSA.

Authorised by:

NAME President, WIOMSA	SIGNATURE	DATE
Endorsed by: L. K. OELLERMANN		17 June 2016
NAME Head of Institution (If other than main applicant)	SIGNATURE	DATE
Accepted by: J. C. GROENEVELD		29 June 2016
NAME Grantee (Principal Investigator)	SIGNATURE	DATE

Note: A contract amendment (not shown) increased funding to the Grantees by a maximum of USD 25 000. Hence the grant totalled USD 165 000 over 3 years.

b) Financial reconciliation for funds disbursed by MASMA to ORI

(Note: Funds disbursed to other partners not shown here)

WIOMSA

ESTUARIZE-WIO

Statement of receipts & expenditure

for the period ending 25 May 2020

Date	Receipts	Amount (USD)	Amount (Rands)
July 2016	1 st tranche	28,250.00	402,999.05
February 2018	2 nd tranche – part 1	8,000.00	52,036.69
June 2018	2 nd tranche – part 2		226,294.24
	Total Receipts		681,329.98
Date	Payments	Amount (Rands)	
August 2016 – July 2019	WIOMSA Symposium	3,047.29	
	Disbursements to partner organisations	269,710.46	
	GIS services rendered - M.Willemse	63,500.00	
	Book (Diop et al. Estuaries of the WIO)	1,978.11	
	Field trip expenses (Ruvu and Tana)	9,200.00	
	Estuarize Website	27,383.41	
	Loose tools & Equipment	2,953.22	
	Postage	133.20	
	Dropbox space	1,198.39	
	Travel & Subsistence for Regional workshops	302,225.69	
	Total Payments	681,329.77	
	BALANCE	0.21	

In addition, ORI contributed **R 92,983.80** to the ESTUARIZE-WIO project over the period.

Co-funding from ORI

Date	Description	Amount (Rands)
June/July 2019	WIOMSA Symposium – Estuarize-WIO delegates	24,785.40
June 2019	GIS Services rendered – M.Willemse	26,500.00
June 2018/19	Field trip - Kenya	40,673.83
July/August 2019	Estuarize-WIO website	1,024.57
	Total Contribution	92,983.80

Appendix 4

Metadata of central dataset compiled and used during Estuarize-WIO, including newly collected field data, existing datasets collected by fisheries departments and other organizations, and open access maps based on satellite remote sensing

FileID	Article (or DOI?)	FileName	Type
2.1.1	2 Residual circulation profile (Hogwane et al.)	BonsSinais_RCM_20170428.csv	Data
2.1.2	2 Residual circulation profile (Hogwane et al.)	BonsSinais_RCM_variables_20170428.csv	Data
2.2.3	2 Residual circulation profile (Hogwane et al.)	BonsSinais_ModelData_Hydrography.csv	Data
3.1.1.	3 Household dependence (Francisco et al.)	20211123_BonsSinais_Social_Tables.xls	Tables
3.2.1	3 Household dependence (Francisco et al.)	20211123_BonsSinais_GovernanceRules_Tables.xls	Tables
3.3.1	3 Household dependence (Francisco et al.)	20211123_BonsSinais_EconomicValuation_Tables.xlsx	Tables
3.4.1	4 Household dependence (Francisco et al.)	20211220_BS_Socioeconomic_Survey_data_Annon.txt	Data
4.1.1	4 Exploring urbanization and critical habitat (Furaca et al.)	20211123_BonsSinais_Groundtruthing_information.xls	Data
4.1.2	4 Exploring urbanization and critical habitat (Furaca et al.)	20211218_BS_Catch_Effort_Length_FishData.xlsx	Data
5.1.1	5 Small scale fisheries of the Bons Sinais (Mugabe et al.)	20210402_TrophicLevelGearsBonsSinais.xlsx	Worksheet
5.2.1	5 Small scale fisheries of the Bons Sinais (Mugabe et al.)	20210409_BonsSinaisSppGearSize_variables.txt	Data
5.3.1	5 Small scale fisheries of the Bons Sinais (Mugabe et al.)	20210409_BonsSinaisSppGearSize_variables.txt	Data
5.3.2	5 Small scale fisheries of the Bons Sinais (Mugabe et al.)	20210409_Selectivity_Beach_seine.R	R-script
5.3.3	5 Small scale fisheries of the Bons Sinais (Mugabe et al.)	Ruvu_Estuary_ImageData_Information.xls	Data
6.1.1	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Ruvu_CTData_May2018.xls	Table
6.1.2	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Ruvu_Fisheries_1_Species_Lists.xls	Data
6.2.1	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Ruvu_Fisheries_2-Estuarize samples 2017-2018.xls	Data
6.3.1	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Ruvu_Fisheries_3- Prawn samples 2017-2019.xls	Data
6.3.2	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Ruvu_Fisheries_4_Macrobrachium 2017-2018.xls	Data
6.3.3	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	na	na
6.3.4	6 Socio-ecological change in the Ruvu (Groeneveld et al.)	Tana_Estuary_ImageData_Information.xls	Data
7.1.1	7 Small-scale fisheries of the Tana (Manyenze et al.)	Tana_Estuary_LCLU_validation.xls	Data
8.1.1	8 Natural resource-use in the lower Tana (Mwamlanya et al.)	Tana_Estuary_Remote_Sensing_Results.xls	Data
8.1.2	8 Natural resource-use in the lower Tana (Mwamlanya et al.)	na	na
8.1.3	8 Natural resource-use in the lower Tana (Mwamlanya et al.)	Climate and precipitation data.xls	Data
8.2.1	8 Natural resource-use in the lower Tana (Mwamlanya et al.)		
9.1.1	9 Regional comparison /socio-ecological systems (Santos et al.)		

Field	Abstract	Analyst	Owner	Taxonomy	Spatial	Coordinate	Time
2.1.1	Depth profile hydrographic data in 11 stations along estuary, 601 observations	AH	UEM	Physical data water	Bons Sinais estuary	18°01' S, 36°58' E	2011-2012
2.1.2	Variable (14) names and units of 2.1.1	AH	UEM	Physical data water	Bons Sinais estuary	18°01' S, 36°58' E	2011-2013
2.2.3	Input data estuarine circulation model	AH	UEM	Input parameters water	Bons Sinais estuary	18°01' S, 36°58' E	2018
3.1.1.	Household information and occupation by age and gender in landing sites (5)	RF	UEM	Household aggregated	Bons Sinais estuary	18°01' S, 36°58' E	2018
3.2.1	Governance system and traditional rules of nature exploitation by landing site (5)	RF	UEM	Household aggregated	Bons Sinais estuary	18°01' S, 36°58' E	2018
3.3.1	Valuation of ecosystem goods and services by landing site (5)	RF	UEM	Household aggregated	Bons Sinais estuary	18°01' S, 36°58' E	2018
3.4.1	Household interview primary data anonymized	RF	UEM	Household data	Bons Sinais estuary	18°01' S, 36°58' E	2018
4.1.1	Names, coordinates and vegetation class of validation points; three files	NF	UEM	Land cover types (historical and seasonal)	Bons Sinais estuary	18°01' S, 36°58' E	2018
4.1.2	Images (6) and season, sensor, resolution and cloud cover information	NF	ORI	Satellite image metadata	Bons Sinais estuary	18°01' S, 36°58' E	1991-2018
5.1.1	Catch, effort, length by gear (6), species (13), landing site (4) and season (2), n= 9565	EV	IIP	Fish, crustaceans	Bons Sinais estuary	18°01' S, 36°58' E	2008-2015
5.2.1	Calculation of weighted trophic level of catch and gear with aggregated data	JS	IIP	Fish, crustaceans	Bons Sinais estuary	18°01' S, 36°58' E	2008-2015
5.3.1	Aggregated length composition of main species (4) in beach seines and chicocotas	JS	IIP	Fish, crustaceans	Bons Sinais estuary	18°01' S, 36°58' E	2008-2015
5.3.2	Variable (9) names and units in 5.3.1	JS	BFE	Fish, crustaceans	Bons Sinais estuary	18°01' S, 36°58' E	2008-2015
5.3.3	Calculate relative selectivity of beach seines from data as in 5.3.1	JS	BFE	Statistical script	Bons Sinais estuary	18°01' S, 36°58' E	2021
6.1.1	Images, date, season, sensor, resolution and cloud cover information	FM	ORI	Satellite image metadata	Ruvu Estuary	6°38'S, 38°87'E	1995-2018
6.1.2	Land Cover validation (see file 6.1.4), classes set for Landsat and Sentinel imagery	FM	ORI	Land cover types (historical and seasonal)	Ruvu Estuary	6°38'S, 38°87'E	1995-2019
6.2.1	CTD readings at Mtai land and Vikundu stations in Ruvu Estuary	BK	TAHRI	Conductivity Temperature Density	Ruvu estuary	6°24'S, 38°52'E	2018
6.3.1	Species observed at Ruvu Estuary	BK	TAHRI	Fish, crustaceans	Ruvu estuary	6°24'S, 38°52'E	2014-2019
6.3.2	Non-random catch data in Ruvu estuary by species, landing site incl. weight and size	BK	TAHRI	Fish, crustaceans	Ruvu estuary	6°24'S, 38°52'E	2017-2018
6.3.3	Non-random prawn catch data from Bagamoyo by species, landing site incl. weight and size	BK	TAHRI	Crustaceans	Ruvu estuary	6°24'S, 38°52'E	2017-2019
6.3.4	Macrobrachium catch data in Ruvu estuary by landing site, incl length and weight	BK	TAHRI	Crustaceans	Ruvu estuary	6°24'S, 38°52'E	2017-2018
7.1.1	Boat, gear, effort, crew, fishing grounds, fish species	FaM	KMFRI	Fish, crustacean	Tana Estuary	2°32'S, 40°32'E	2018
8.1.1	Images, date, season, sensor, resolution and cloud cover information	FM	ORI	Satellite image metadata	Tana Estuary	2°32'S, 40°32'E	1987-2019
8.1.2	Land Cover validation from ground photographs (x500, 08/2019)	FM	ORI	Land cover types (historical and seasonal)	Tana Estuary	2°32'S, 40°32'E	1987-2020
8.1.3	Summary remote sensing analysis (No. pixels & % cover) for Landsat and Sentinel images	FM	ORI	Land cover types (historical and seasonal)	Tana Estuary	2°32'S, 40°32'E	1987-2021
8.2.1	Household info, fishing, catch, products and market	HM	KMFRI	Household data	Tana Estuary	2°32'S, 40°32'E	2018
9.1.1	Average ambient air temperature (celsius) and precipitation (mm) (12 months)	JG	ORI	Temperature Precipitation	Bons Sinais, Ruvu, Tana	18° S to 3° S	na