

Sea cucumbers in the western Indian Ocean

Improving management of an important but poorly understood resource

Principal Investigators:

Chantal CONAND

Ecomar Laboratory

Reunion University

97715 Saint Denis, Reunion, France

Email: conand@univ-reunion.fr

Nyawira MUTHIGA,

Wildlife Conservation Society

Kibaki Flats No. 12

P.O. Box 99470

Mombasa, Kenya

Email: nmuthiga@wcs.org

Co-Investigators:

Kenya - Jacob OCHIEWO, Kenya Marine & Fisheries Research Institute

Madagascar - Richard RASOLOFONIRINA, IH-SM and Aqua-lab

Reunion - Patrick FROUIN, ECOMAR, Reunion University

Seychelles - Riaz AUMEERUDDY, Seychelles Fisheries Authority

Sweden - Maricela DE LA TORRE-CASTRO, Stockholm University

Tanzania - Yunis MGAYA, University of Dar-es-salaam

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Fax: +255 24 2233852
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ABSTRACT

Across the Western Indian Ocean harvesting of sea cucumbers is predominantly carried out by artisanal fishers. Worldwide production of beche-de-mer that is processed from sea cucumbers is currently not sufficient to meet the demand of the Asian Market and pressure to continue fishing is still very high. This coupled with declining stocks and weak management systems indicate that sea cucumber stocks are unlikely to recover to sustainable levels in the near future.

The need for improved management of the sea cucumber fisheries in the WIO led to the initiation of a three-year multi-country regional research project funded by the Marine Science for Management program of the Western Indian Ocean Marine Science Association. First, the project aimed to document and evaluate the knowledge available on sea cucumbers in the region. This was necessary to gain an understanding of the challenges of the fishery in order to guide the design of future research and management interventions. Second, the project sought to fill key gaps in information by conducting research studies on the ecology, biology and socioeconomics of sea cucumbers in five countries in the region. The project involved a multi-disciplinary team from Kenya, Madagascar, Reunion (France), Seychelles and Tanzania. All these countries with the exception of Reunion have sea cucumber fisheries allowing for comparisons across different fishing intensities, socioeconomic conditions and capacity for management.

The main components of the project included, ecological assessments and species inventories; studies on the reproductive biology of the key commercial species; studies to assess the effectiveness of marine protected areas in the management of sea cucumbers; studies on the socioeconomics and management of the fishery; and training fisheries managers on the taxonomy, fisheries biology and management of sea cucumbers. This volume summarizes key research findings and the main recommendations from the project. The volume is targeted at institutions that have a stake in maintaining the long-term productivity and sustainability of fisheries and natural resources including fisheries and conservation managers, local communities that depend on these resources and donors especially those who have an interest in community resource management and alternative livelihoods.

The main findings of the project were that the sea cucumber fisheries in most of the studied countries continued to decline due to overexploitation and persistent and systemic governance challenges. The key recommendations detailed in this report include improving management capacity and planning, addressing the ecological and socioeconomic knowledge gaps, exploring alternative livelihoods and diversification, and improving stakeholder engagement and regional coordination. For sea cucumber fisheries to improve and to continue to contribute to livelihoods, there is a need for coordinated national commitments to develop and implement management systems that improve the likelihood of achieving sustainability of this fishery.

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INTRODUCTION

Countries in the Western Indian Ocean (WIO) have traded sea cucumbers (holothurians), for centuries, yet little is known about stocks, fishing practices and the socioeconomic factors driving this fishery. A previous global review indicated that the WIO fishery contributed approximately one fifth of the worldwide production of beche-de-mer between 1994 and 2001 (Conand 2006a). The sedentary nature of sea cucumbers, the high value and demand for beche-de-mer in the international market, the low cost of processing, make sea cucumbers very vulnerable to over exploitation (Lovatelli *et al.* 2004; Bruckner 2006; FAO 2013). Reports of decreased production, increasing contribution of low value sea cucumbers in the catch and the use of more intensive gears such as SCUBA, as well as increased fishing time and reduced sizes, indicate the overexploitation of this valuable fishery in the WIO (Coleson & Jiddawi 1996; Conand & Byrne 1993; Conand 2004a; Conand 2006a; Conand & Muthiga 2007).

Because sea cucumber fisheries are predominantly artisanal in the WIO, they provide a vital source of income through employment and livelihoods for fishers and their dependents (Jiddawi & Ohman 2002; Conand & Muthiga 2007; FAO 2013). These shallow water fisheries also provide additional social benefits because they are one of the few fisheries that are accessible to both women and children. The decline of sea cucumber stocks in the region would therefore be expected to have negative implications on the lives of coastal communities. In addition, studies are increasingly showing that sea cucumbers play a crucial ecological role (Uthicke 1999; 2001a; Mangion *et al.* 2004) and their removal could negatively impact the resilience of coastal ecosystems and further exacerbate the effects of climate change.

Given that the region is the fifth producer of sea cucumber products in the world, and that the fishery contributes directly or indirectly to the food security and livelihoods of poor coastal communities, the case for improving the management of this valuable resource is a strong one. Poverty is one of the causes of over exploitation, yet healthy fisheries can contribute to poverty reduction through a sustainable supply of economic benefits. Weak governance of fisheries that occurs across the region however reduces these benefits and further exacerbates and contributes to overfishing. The challenge therefore is developing a suite of management interventions that meet the development goals of WIO countries of food security and poverty alleviation and that sustain healthy ecosystems. This requires comprehensive scientific information that incorporates environmental, biological and social aspects of the fishery. The lack of such information provided the impetus for a regional project funded by the Western Indian Ocean Marine Science Association (WIOMSA) through the Marine Science for Management Program (MASMA). The Regional Sea Cucumber Project was launched in 2005 (Conand *et al.* 2006) and this publication contains scientific information and recommendations for management produced through this project.

The Regional Sea Cucumber Project aimed to produce scientific information and training in order to strengthen management for the conservation and sustainable use of sea cucumbers in the WIO region. The information collected was intended to form the foundation for a better understanding of the sea cucumber fisheries that would inform the development of effective fisheries management interventions. Training in sea cucumber taxonomy, biology and fisheries management would also provide the capacity for monitoring and evaluating management interventions. The project focused on studies in Kenya, Madagascar, Reunion, Seychelles and Tanzania. These countries were selected because they had differing intensities of fishing and levels of management and the similarities and differences in the biodiversity and fisheries within these countries were expected to generate information that would be of regional as well as global relevance. The project team included scientists with biological and socioeconomic expertise that aimed at addressing the following broad questions as outlined in the project proposal:

1. What is the status of the sea cucumber resources in the WIO in general and what ecological factors control the distribution and biogeography of sea cucumber in the WIO;
2. Which sea cucumber species are adequately protected and which are adversely affected by fishing and to what extent;
3. What are the reproductive and recruitment patterns of key commercial species in the region;
4. What are the national marine resource use patterns and how do sea cucumbers contribute to (a) national economies and (b) livelihoods of local communities in the selected WIO countries; and
5. What management programs (including marine protected areas) are in place and what are the barriers preventing effective management of the sea cucumber fisheries in the WIO region.

A final objective was to increase the capacity of practitioners in the WIO in sea cucumber biology, taxonomy and assessment methodologies.

This report is the final output of the regional sea cucumber project. The report is organised according to the main areas of the research studies; an ecological component that addressed Questions 1 and 2; a biological component to address Question 3 and; a socioeconomic and management component that addressed Questions 4 and 5 above. Scientists with expertise in the various subjects from the five study countries as well as associated partners and students collaborated in the project. This report and the review that was conducted at the start of the project (Conand & Muthiga 2007) is targeted for marine resource managers, scientists and communities and should contribute to improving the management of this valuable fishery in the western Indian Ocean.

LITERATURE REVIEW

A comprehensive literature review of publications on sea cucumbers in the WIO was carried out at the start of the regional project and published in a book (Conand & Muthiga 2007¹). The source materials included information from peer-reviewed publications, theses/dissertations and project reports on aspects ranging from ecological, biological and socioeconomic to fisheries management. Individual chapters on the status of sea cucumbers in Kenya, Madagascar, Reunion, Seychelles and Tanzania that had active fisheries and or research programs were included and more than 121 citations were referenced. The following overview provides a summary of the information that was collected and collated from the review.

Taxonomic and ecological studies

Some of the earliest studies on sea cucumbers were taxonomic studies and surveys by Clark & Rowe (1971) in the Indo-Pacific (including East Africa and Madagascar), Michel (1974) in Mauritius, Humphreys (1981) in Mida creek Kenya, Sloan (1982) and Clark (1984) in the Seychelles, and Cherbonnier (1988) in Madagascar. The work by Cherbonnier (1988) resulted in the description of 47 new species and two new genera. Between the mid 1990s and 2000s surveys, inventories and taxonomic studies were also conducted in the Comoros, Kenya, Reunion, Mauritius, Madagascar, Mayotte, Seychelles, South Africa and Tanzania, (Arakaki & Fagoone 1996; Conand 1999; Massin *et al.* 1999; Samyn 2000; Samyn & Vanden Berghe 2000, Bolton *et al.* 2001; Samyn *et al.* 2001; Conand & Mangion 2002; Rowe & Richmond 2002; Conand 2003; Samyn 2003; Samyn & Massin 2003; Samyn & Thandar 2003a; 2003b; Thandar & Samyn 2004a; 2004b; Massin *et al.* 2004; Rowe & Richmond 2004; Conand *et al.* 2005; Pouget 2005; Samyn *et al.* 2005; Rowe & Massin 2006; Samyn *et al.* 2006; Mulochau *et al.* 2007). These studies resulted in the description of

¹Copies of the book are available from the Executive Secretary, Western Indian Ocean Marine Science Association, P.O. Box 3298 Zanzibar Tanzania

several new species: *Bohadschia atra* (Massin *et al.* 1999), *Holothuria arenecava* (Samyn *et al.* 2001), *Labidodemas quadripartitum* (Massin *et al.* 2004), and *Actinopyga capillata* (Rowe & Massin 2006). *Bohadschia subrubra* was redescribed by Massin (*et al.* 1999) and there were revisions of other genera (Samyn & Massin 2003; Thandar & Samyn 2004b; Thandar 2007). Although several identification guides on sea cucumbers existed for the region (Clark & Rowe 1971; Richmond 2002; Samyn 2003), there was overall a very low taxonomic expertise in most countries.

These taxonomic studies showed a rich and diverse assemblage of sea cucumbers and Madagascar was the most speciose with 125 species (Cherbonnier 1988, Massin *et al.* 1999). Species from the Order Aspidochirotida and family Holothuridae and Stichopodidae dominated the assemblage and very few species belonging to the Orders Dendrochirotida and Apodida were recorded. A preliminary zoogeographical analysis based on intensively sampled collections for Kenya and Tanzania (Pemba Is.) by Samyn & Tallon (2005) indicated that the sea cucumber biota of the region was broadly divided into three biogeographic provinces; the Red Sea and associated Arab Basin, an area stretching from the horn of Africa to southern Mozambique, and southern Africa. However, the data of species richness of individual countries and the region as a whole were an underestimation as evidenced by the fact that new species continued to be discovered, new records of species not previously recorded continued to be reported, and that deeper water, cryptic and small sized species were under sampled.

Although sea cucumbers occur in a variety of ecosystems most of the studies in the region focused on shallow water coastal ecosystems such as coral reefs, seagrass beds and hard substrate banks. Distribution and abundance information was available for Kenya (Anon 1993; 1994; Muthiga & Ndirangu 2000), Mauritius (Clares 1998; Luchmun *et al.* 2001; Mrowichi 2007), Mayotte (Pouget 2005; Mulochau *et al.* 2007), Reunion (Conand & Mangion 2002; Conand 2003; Fabianeck & Turpin 2005) and Seychelles (Aumeeruddy & Skewes 2005; Aumeeruddy *et al.* 2005; Coeur de Lion 2005). Results showed high variability in the relative abundance of sea cucumbers. *Holothuria atra* and *H. leucospilota* dominated in Kenya and Reunion averaging 0.04 ind.m⁻² in Kenya (Muthiga & Ndirangu 2000) to ~5 ind.m⁻² in Reunion (Conand 2003). The densities were generally higher in reef lagoons and channels than reef flats and seagrass beds in Kenya (Muthiga & Ndirangu 2000) and in back reef than inner reef sites in Reunion (Conand 2003; Fabianeck & Turpin 2005). In the Seychelles, *H. atra* dominated at a density of 5.61 ind.ha (Aumeeruddy 2007) and in Madagascar where surveys focused on commercial species, the highest densities of *Holothuria notabilis* (6000 kg.ha) were reported in seagrass beds (Mara *et al.* 1997; Conand 1999).

Many factors influence the distribution and abundance of sea cucumbers including habitat, competition and predation, recruitment and fishing yet few studies focused on these aspect in the region. A study by Conand (1996) showed that *H. atra* populations differed in morphological characteristics in different habitats at La Saline reef complex in Reunion. Individuals were larger and occurred in lower densities in the outer reef flat indicating the possible influence of environmental factors such as wave energy. On the other hand, individuals were smaller and occurred in higher densities in the back reef and inner reef habitats and showed higher levels of reproduction through fission which the author concluded influenced the population densities. A comparison of sea cucumber densities and diversity within marine protected areas and at fished sites in Kenya by Muthiga & Ndirangu (2000) also showed that fishing had an impact; higher densities and diversities were reported in fisheries closures than at fished sites.

Despite the important role that sea cucumbers play in the ecology of the marine ecosystems they inhabit (Uthicke 1999, 2001a; 2001b), few studies have been carried out on this aspect in the WIO. One study that evaluated the effects of nutrition on the distribution of *H. atra* and *H. leucospilota* (Mangion *et al.* 2004) reported that these species were more abundant at more eutrophic than oligotrophic sites and that the species were able to discriminate soft bottom patches with higher nutritive value. Given that many sea cucumber populations are depleted through overexploitation,

an understanding of the critical role that they play in the ecology of reefs or seagrass beds would provide an additional rationalization for improved management.

Biological and reproductive studies

Biological information including mode and timing of reproduction, the population sex ratio and the size at sexual maturity are crucial for fisheries management. Some of the earliest reproduction studies in the region were on fission in *H. atra* (Conand 1996), *H. leucospilota* (Conand *et al.* 1997) and *Stichopus chloronotus* (Conand *et al.* 1998a; Conand *et al.* 2002) as well as other studies on reproduction (Jaquemet *et al.* 1999; Barrère & Bottin 2007) in Reunion. Studies on the genetic variation in population structure of fissiparous and sexually reproducing populations of *S. chloronotus* and *H. atra* in Madagascar, Reunion and Australia indicated that although genetic diversity was reduced in some of the WIO populations, it was not generally a common factor for all of them (Uthicke *et al.* 2001; Conand *et al.* 2002; Uthicke & Conand 2005b). The presence of both modes of reproduction therefore served different purposes - fission served to maintain the population, while sexual reproduction served to disperse larvae over long distances thus enhancing genetic variability (Uthicke *et al.* 2001; Uthicke & Conand 2005).

Seasonal sexual reproductive cycles that are related to temperature are common in sea cucumbers (Conand 1981, 1982, 1989; Smiley *et al.* 1991; Conand 1993a, 1993b; Conand *et al.* 2002). Although tropical species were thought to reproduce year round, new findings over the years have shown a more complex pattern. In general the onset of egg and sperm production (gametogenesis) has been correlated with environmental factors such as photoperiod and water temperature (Conand 1989; Morgan 2000; Ramofafia *et al.* 2000) while spawning is suggested to be triggered by changes in water temperature (Conand 1989; Smiley *et al.* 1991; Ramofafia *et al.* 2000) food availability (Cameron & Frankboner 1986; Hamel *et al.* 1993), light intensity (Cameron & Frankboner 1986), water turbulence (Engstrom 1980), salinity (Krishnaswamy & Krishnan 1967) and phytoplankton blooms (Himmelman 1980).

The sexual reproductive cycles of previously studied sea cucumbers in the WIO varied with little correspondence with the geographical area or the species. For example, species closer to the equator (40° - 70S) displayed either an annual pattern with a single extended spawning period (*Holothuria arenacava* in Kenya; Muthiga 2006) or a biannual pattern with two spawning periods (*Holothuria scabra* in Tanzania; Mmbaga 2002; Kithakeni & Ndaró 2002). Interestingly, further from the equator (21° - 23°S) in Madagascar, *H. scabra* also displayed an annual pattern with a single extended spawning period (Rasolofonirina *et al.* 2005) while *S. chloronotus* displayed a biannual pattern (Conand *et al.* 2002). While the studies concluded that water temperature (Conand *et al.* 2002; Kithakeni & Ndaró 2002; Rasolofonirina *et al.* 2005) and light (Muthiga 2006) were the main drivers of the reproductive cycle, Rasolofonirina *et al.* (2005) also suggested that day length and salinity could play a role in the reproduction of *H. scabra* in Madagascar. The Reunion population of *S. chloronotus* was unique in that sexual reproduction occurred in the warm season and fission in the cool season (Conand *et al.* 1998a; Conand *et al.* 2002). The fact that the main oceanographic parameters (water temperature, light intensity, ocean productivity) that are reported to entrain reproduction in sea cucumbers occur during the same period in the WIO region (McClanahan 1988), suggests that experimental studies would have to be carried out to confirm the specific cue for the onset of gametogenesis and spawning in individual species.

These studies on reproduction not only provided the first sets of data that could be used for fisheries management such as the timing of spawning that would allow the setting of closed seasons and mariculture, but also size at sexual maturity for the setting of minimum size limits. In addition, the ability of sea cucumbers to reproduce through fission has generated some interest in using fission in mariculture in Mauritius (Laxminarayana 2006). Studies on sea cucumber growth rates and mortality that are also useful for management however have not been conducted in the

WIO. This is partly because conventional tagging methods that are used for measuring growth are ineffective in sea cucumbers (Conand 1989b; Purcell *et al.* 2006a).

Socioeconomics and fisheries management studies

Sea cucumbers in the WIO are primarily traded as the dried body wall (beche-de-mer or trepang) and very little local consumption occurs. The fisheries have existed in some countries of the region for centuries with some of the oldest catch records dating back to the 1800's reported in the Madagascar (Petit 1930) and the Seychelles (Marguerite 2005). Despite this long history, the fishery continued to evolve with little knowledge of the stock size, biology and ecology of target species, fishing practices and socioeconomics of the fishery. Preliminary assessments indicated generally poorly managed fisheries in the Comoros, Kenya, Tanzania, Madagascar, Mauritius, Mayotte and Mozambique (Darwall 1996; Jiddawi 1997; Guard 1998; Semesi *et al.* 1998; Horsfall 1998; *Mgaya et al.* 1999; Muthiga & Ndirangu 2000; *Marshall et al.* 2001; Mmbaga & Mgaya 2004; *Rasolofonirina et al.* 2004; Beadle 2005; Pouget 2005; Samyn *et al.* 2005; Conand & Muthiga 2007) and relatively well managed fisheries in the Seychelles (Aumeeruddy & Payet 2004; Aumeeruddy & Skewes 2005; Robinson *et al.* 2006; Aumeeruddy & Conand 2008).

Throughout the region, the fishery followed a generally similar pattern, periods of high production followed by declines except in the Seychelles where production showed a dramatic increase in the early 1990's (Marguerite 2005). However, due to a lack of consistent trade and production data, it was difficult to reliably quantify the trade in beche-de-mer (*Marshall et al.* 2001; Conand 2004a, 2006a). Starting in the late 1900s, some countries of the WIO periodically reported production information to FAO and despite the inconsistencies in the data, this was the most reliable information on these countries. These data for Kenya, Madagascar, Tanzania and Mozambique were summarised by Conand (2006b) who estimated that the fisheries in the FAO area 51 which includes some countries in the WIO, contributed approximately 30% of the worldwide production of beche-de-mer between 1994 and 2001.

In general, countries in the WIO not only reported decreased production (Conand 2006b), but increasing contribution of low value sea cucumbers in the catch, switching to more efficient gears such as SCUBA, as well as increased fishing time and reduced sizes all indicating over exploitation. Up to thirty species of sea cucumbers were harvested in Madagascar (Mara *et al.* 1997; *Rasolofonirina et al.* 2004), 17 in Kenya (Muthiga & Ndirangu 2000), 21 in the Seychelles (Aumeeruddy *et al.* 2005) and 22 in Tanzania (*Marshall et al.* 2001; Mmbaga & Mgaya 2004). Fishing was mainly artisanal by gleaning except in the Seychelles where it was semi-industrial.

Most countries had legislative and regulatory instruments that governed fisheries and in some cases regulations were specific for sea cucumbers (Muthiga & Ndirangu 2000; *Marshall et al.* 2001; Aumeeruddy & Payet 2004; Beadle 2005). Fisheries catch monitoring programs were present in nearly all the countries but were often unreliable due to poor collection and storage of catch and export data, except in the Seychelles where a system of log-books was established in 1999, while catch statistics were not collected at the species level (Conand & Muthiga 2007). Management regulations and interventions included area closures, size limits, gear restrictions especially the ban of SCUBA, licensing and research (Conand & Muthiga 2007). A mariculture project in Madagascar (*Jangoux et al.* 2001; *Rasolofonirina et al.* 2004; *Rasolofonirina* 2005; *Rasolofonirina & Jangoux* 2005) includes a restocking component for community managed areas. In most countries of the region therefore, a lack of targeted management and ineffective or poorly implemented regulations reduced the contribution of this valuable resource to the fisheries sector.

Little is known about the socioeconomics of the sea cucumber fishery in the WIO. Some socioeconomic information can be derived from general assessments of the fishery for Kenya (Muthiga & Ndirangu 2000; Beadle 2005), Seychelles

(Marguerite 2005) and Tanzania (Semesi *et al.* 1998) while Madagascar received more attention especially after the development of mariculture (Rosa 1997; Salimo 1997; Rasolofonirina & Conand 1998; Rasoarinoro 1990; Be 2002; Rasolofomanana 2006). These assessments indicated that except for the Seychelles, most of the fisheries were small-scale and undertaken by men, women and children through gleaning, skin and SCUBA diving. However, there was little information on important aspects of the socioeconomic conditions of the communities involved in the fishery such as the level of dependency on the fishery, the contribution of sea cucumber fishing to household incomes, details on the processing and trade and other aspects including conflicts with migrant fishers that are relevant for management.

METHODOLOGY

The project commenced with two start-up workshops focusing on 1) the overall implementation of the project including roles and responsibilities of project investigators that was held in January 2006 in Mombasa, and 2) the conceptual framework and methodologies for the socioeconomic studies that was held in September 2006 in Dar-es-salaam. The research questions (detailed in the objectives above) were grouped into three main components; an ecological component that addressed Questions 1 and 2; a biological component to address Question 3 and; a socioeconomic and management component to address Questions 4 and 5. Scientists with expertise in the various subjects discussed methodologies and developed data templates for the various components. Training exercises were also conducted to strengthen the skills of the researchers on the ecological, taxonomic and reproduction methodologies. The methods and datasheets that were designed for the project were summarised in Muthiga & Conand (2006) for the ecological and biological component and de la Torre-Castro *et al.* (2007) for the socioeconomic component and are outlined below.

Taxonomic and ecological Studies

The ecological studies focused on providing information on the general status of sea cucumber resources, the ecological factors that control their abundance and distribution, and assessing the impacts of fishing and marine protected areas on commercial sea cucumber species. Ecological surveys were planned for Kenya, Madagascar, Reunion and Tanzania mainland.

Species inventories

Within each country, a comprehensive literature search was carried out and species lists were compiled and updated as new species were encountered in the field surveys. The surveys were carried out while walking in shallow lagoons, and snorkelling or SCUBA diving in deeper waters. All sea cucumbers that were encountered were identified and the location, site, habitat and depth were noted. Individuals that could not be readily identified were photographed, collected, fixed in 6% formalin for an hour and stored in 90% alcohol for future identification. Whenever possible, geographical coordinates were taken using a hand-held Global Positioning System (GPS) unit.

Abundance and distribution

Abundance data were collected while walking in shallow lagoons, snorkelling or SCUBA diving in deeper waters using the belt transect and timed-search sampling methods. All sampling was done during the day at low tide. The belt transect was marked by a 100m long nylon rope that was laid perpendicular to the shore. All sea cucumbers encountered within a 2m area on either side of the line were counted and identified to species, and the location, habitat, depth and management type were noted. Three to five belt transects were completed at each site. For the time sampling method, the observer walked, swam or used SCUBA and moved haphazardly perpendicular to shore noting every sea cucumber

encountered and the time encountered for a 40-minute to one-hour period. A one-hour time search period covers an area of ~1000m² (McClanahan 1989). Sea cucumber abundances were calculated by estimating the mean number (\pm SEM) of sea cucumbers in each habitat and site. The species richness was analysed by plotting cumulative species time curves and calculating the Simpson's Index. Comparisons between sites, depth, habitat and management were done using multivariate analysis.

Marine protected area (MPA) effectiveness

In order to gain a better understanding of how fishing affected sea cucumber populations, a comparative study of sea cucumber populations in fully protected and unprotected reefs in Kenya was carried out. The experimental design consisted of surveys of 3 fully protected areas (Kisite, Mombasa and Malindi marine parks), three unprotected areas (Kanamai, Diani and Vipingo) and Ras Iwatinde a partially protected area in the Mombasa marine reserve. Surveys used the belt transect and time search methods detailed above. To test for differences in the abundances, diversity and species richness between habitats and between management treatments, data were pooled for comparison. Data were initially tested for normality using cumulative frequency distributions (Sokal & Rohlf 1981). Coefficients of dispersion ($CD=s^2/x$) of sea cucumber population densities were analysed to determine spatial distribution and species richness was determined by species-time and species individual curves. Regression analysis was done to express species richness in terms of time (t) and individuals (I). Multivariate analysis (with nested ANOVA) was also performed to test how habitat parameters (substrate cover and rugosity) related to sea cucumber population parameters under the two management categories.

Biological and reproductive studies

There were three main objectives for this component; 1) to study the reproductive cycles and the environmental factors affecting reproduction for six species of sea cucumbers; 2) to investigate the effects of fishing on life history parameters such as reproductive output and sex ratio on the commercial species *Holothuria fuscogilva* and *H. scabra*; and 3) to investigate the recruitment patterns of commercial species. Studies were carried out on the reproductive biology of *Actinopyga echinites* and *H. leucospilota* in Reunion, *H. fuscogilva* and *H. scabra* in Kenya, *H. notabilis* and *Stichopus horrens* in Madagascar, *H. atra* in the Seychelles and *H. scabra* in Tanzania.

Annual reproductive cycles

The reproductive cycles of the different species were investigated using two standard methods; 1) measurements of monthly changes in the gonad index; and 2) observations of monthly changes of the gonad maturity stages (Conand 1993; Conand *et al.* 2002). The gonad index method is useful since it allows for the collection of large amounts of data with relative ease compared to histological preparations, but has the disadvantage of yielding meaningful results only when there is no significant relationship between the size of the animal and the gonad index (Grant & Tyler 1983). Hence the relationship between individual size and the gonad index was estimated for the studied species. The feeding cycle was also investigated by measuring monthly changes in gut size using gut index as a proxy for seasonal changes in feeding activity (Sonnenholzner 2003; Muthiga 2006). Since the reproductive cycle maybe highly variable, at least twenty individuals were collected monthly for up to two years, to ensure adequate data from both sexes except when the reproductive cycle was very clear after the first year of analysis.

At each site, monthly sampling was conducted by snorkel at low tide or using SCUBA in deeper waters. Individuals of the studied species were collected regardless of the individuals' size and relaxed in seawater mixed with MgCl₂ (70g/l)

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to minimize evisceration. Each individual was measured (mm) from the mouth to the anus (body length or Total length), dissected, the coelomic fluid was drained and the body wall, the gut and gonad were separated and individually weighed (to the nearest 0.1gm). The sex of each individual was noted and the gonads were preserved in 7% formalin and a sub sample was preserved in Bouins fluid for histological analysis. Individuals that could not be sexed were noted as indeterminate. The weight of the body wall minus all organs was weighed (body wall weight or Gutted weight) and the gonad and gut indices were calculated using the formula:

$$\text{Gonad (or Gut) index (\%)} = \text{Gonad (or Gut) wet weight/gutted wet weight} \times 100$$

The average (\pm SEM) gonad and gut indices for each month for males and females were calculated and the annual patterns of reproduction and feeding were illustrated by plotting average monthly indices over the sampling period. Averages (\pm SEM) of morphological characteristics including total length (mm), gutted weight (gm), gonad and gut weights and gonad and gut indices were also calculated for each species. The differences between the sexes in these morphological characteristics were compared using ANOVA.

The variability in reproduction between the sexes, between the months and between the years was determined for each species by testing the gonad index data for normality using the Shapiro-Wilk W test if found not to be normally distributed, the Kruskal-Wallis test was then used to test for differences between months and between years. The influence of individual body size on gonad growth was determined by a correlation of the body wall wet weight (g) against the gonad index (%), and, the differences between the sexes was determined through a single factor ANOVA of gonad indices of females against males. The level of sexual synchrony between the sexes was determined by a correlation of the mean monthly gonad indices of females against the mean monthly gonad indices of males.

Gonad indices were also used to elucidate the presence or absence of lunar periodicity. The average gonad index for each lunar day measured during the peak reproductive period was calculated and plotted against the lunar day (new moon = lunar day 0). The relationship between gonad growth and lunar periodicity was then tested using a correlation of the gonad index and lunar day.

Gametogenesis and gonad maturity stages

The morphological characteristics of sea cucumber gonads are useful for understanding the progression of the reproductive cycle. Some species have gonads with tubules that are roughly the same length that all proceed through the gametogenic cycle at the same time, while other species have gametogenesis occurring in different stages in tubules of different lengths referred to as the Tubule Recruitment Model (TRM). It is important to know which type of gonads occur in the species of interest (Hamel & Mercier 1996 ; Sewell *et al.* 1997 ; Ramofafia & Byrne 2001). For gonads with tubules of roughly equal length, the tubule length was measured from gonad base to the tip of the tubule and the tubule diameter was measured on 5 tubules using a microscope (with micrometer) at a position in the middle of each tubule. The consistency of the gonad and presence of atresia (ova that are disintegrating) were noted macroscopically. In addition, the diameter of oocytes was measured on 30 oocytes (per individual female) that were carefully removed from the middle section of a tubule and placed onto glass slides and measured using an ocular micrometer. The size frequencies of oocytes of each monthly sample were plotted to elucidate whether there was a clear oocyte modal size or several modes.

The maturity stage of each gonad was noted using a five-point scale - Resting (I), Immature (II), Growing (III), Mature (IV), Post-spawning (V) described in Conand (1981; 1993) and the percentage of individuals in each maturity stage was

calculated and plotted against the month. Since the maturity stages of males and some female gonads are difficult to differentiate macroscopically, sections of the preserved gonad tubules were prepared using standard histological techniques and observed under a microscope to verify the maturity stages.

Sex ratio and size at sexual maturity

The sex ratio and size at sexual maturity for individual species are important parameters for fisheries management. The sex ratio of all the species was calculated and tested for deviation from unity using the Chi-squared test. The size at sexual maturity was estimated from the cumulative size frequencies (calculated using the gutted weight) as the size at which 50% of the samples were at maturity stage 3-5 as devised by Conand (1981; 1993).

Reproductive output

The reproductive output was investigated during the peak reproductive period (defined as the period when gonad indices peaked) from measurements of; 1) the gonad size measured as the gonad wet weight (g); 2) the gonad tubule length (mm); and, 3) fecundity measured as the number of oocytes a female produced during the peak reproductive period (oocytes/female).

Fecundity was estimated by calculating the average number of oocytes in the tubules of ripe gonads. Oocytes were extracted from a sub sample of previously preserved gonads (described above) that was weighed (to the nearest 0.001 g) and macerated using a pestle and mortar. The mixture was passed through a coarse filter to remove tubule tissue and the oocytes were mixed in 1000 ml of filtered water. Five aliquots (0.1 ml) were taken while the mixture was stirred with a magnetic stirrer. The oocytes in each aliquot were counted and averaged and the absolute fecundity was calculated using the formula:

Absolute fecundity = the average number of oocytes per aliquot x the dilution factor x the proportion of the weight of the subsample of gonad to the total gonad weight

The relationship between gonad size and reproductive output was tested through regressions of individual and monthly averages of gonad weight against tubule length, gonad weight against fecundity, and tubule length against fecundity.

Environmental factors

The environmental factors including temperature (°C), light (Einstein/m²/day) and rainfall (mm) were collated from various sources. Air temperature and light data for Kenya and Madagascar were obtained from NOAA satellite data (Casey *et al.* 2010), while rainfall was obtained from the Kenya Meteorological station in Mombasa. Seawater temperature data for Reunion were obtained from a 10-year series from in-situ gauges (Conand *et al.* 2007), while light and rainfall were obtained from the French meteorological department (www.meteofrance.com). The monthly averages were calculated for each environmental parameter and correlated with the monthly gonad indices for each species at the respective sites.

Recruitment surveys

Since the study of recruitment in sea cucumbers is problematic due to the cryptic nature of recruits and the high variability of recruitment (Shiell 2004a; 2004b; Hearn *et al.* 2005), the study focused primarily on recording when recruits of different species were observed in the field. Hence recruitment surveys were carried out when studying the distribution of sea cucumbers or during the monthly sampling for reproduction. Upon the initial observation of small individuals (< 100mm) of the species studied for reproduction, the habitat, date, location, species and length of individuals were recorded. In addition, 30-minute timed searches were also carried out 2-3 months after the spawning season, for species that showed a defined spawning period. Twenty quadrats (1m²) were also haphazardly tossed and carefully searched for recruits. Observers were careful to distinguish small individuals that were from sexual reproduction and those that were produced through asexual reproduction (fission) for *H. atra*, *H. leucospilota*, and *S. horrens*. In addition, care was taken not to confuse *S. horrens* and *S. monotuberculatus* that have similar features especially in the juvenile stages.

Socioeconomics and fisheries management studies

The two main objectives for this component were; 1) to document the status of the fishery at the national level including, the marine resource use patterns and resource use perceptions, the social and economic characteristics of the fisher communities, the contribution of sea cucumbers to the national economies and community livelihoods of the studied countries; and 2) to analyze the national management systems in the different countries including the general management interventions and strategies, legislation, policies and regulations, fisheries catch and trade monitoring, licensing, surveillance, and establishment of MPAs.

Five standard methods were used to collect data including questionnaires, semi-structured interviews, key informant interviews, focus group discussions and network analysis described below. Since socioeconomic studies involve interactions with people, cultural norms were taken into consideration and recommended approaches (Bunce *et al.* 2000) were followed during the interviews. Much of the work was focused on selected sites in Kenya (Malindi, Mombasa, Majoreni, Shimoni and Vanga), Madagascar twelve villages in the south-west around Toliara, Seychelles (Mahe Is.) and Tanzania mainland (Kunduchi, Kitoni, Buyuni, Utende) and in eight villages in Zanzibar. These sites coincided with areas investigated in the ecological and biological components of the project.

Questionnaires

Household and other basic socioeconomic information was collected using the guidelines and questionnaires that were discussed during the start-up workshop (de la Torre-Castro *et al.* 2007). A sample of respondents was chosen haphazardly at target sites that included fishers, sea cucumber fishers, processors and traders depending on the location. The questionnaires provided general information on the socioeconomic conditions of the studied communities.

Semi-structured interviews

Respondents were also haphazardly chosen for the semi-structured interviews including sea cucumber fishers, traders, exporters and management authorities. Interviews were conducted using semi-structured questionnaires composed of open-ended questions that could be qualitatively and quantitatively analysed (Kvale 1996). Interviews were either conducted at the landing beaches or in the homes of the respondents. Follow-up interview sessions were conducted to pursue new lines of questions and clarify issues raised from previous questionnaires.

Key informant interviews

Opinion leaders (key informants) were targeted and interviewed. Key informants were chosen using the 'snowball' method of selecting persons that were pointed out by locals. These informants were chosen to give additional insight into areas that needed clarification and to help in validating the information collected.

Focus group discussions

Focus group discussions were composed of groups of 5 to 10 persons that were organised in advance allowing the group to pick the venue. Several focus group discussions were organised in each area depending on the issues identified after the general questionnaires. Discussions were guided by a set of open-ended questions focusing on the sea cucumber fishery and its management and conducted on days that fishers did not go fishing such as Fridays due to religious reasons. The group discussions also served to enhance interaction between the respondents and interviewers.

Structure and network analysis of the fishery

The general structure of the sea cucumber trade system in each country was reviewed using the framework developed by Conand (1997; 1998). In addition, de la Torre-Castro *et al* (2007) design and more complex conceptual model that was used to develop a better understanding of all the key elements of the network of the sea cucumber fishery using Zanzibar as a template (**Fig. 1**).

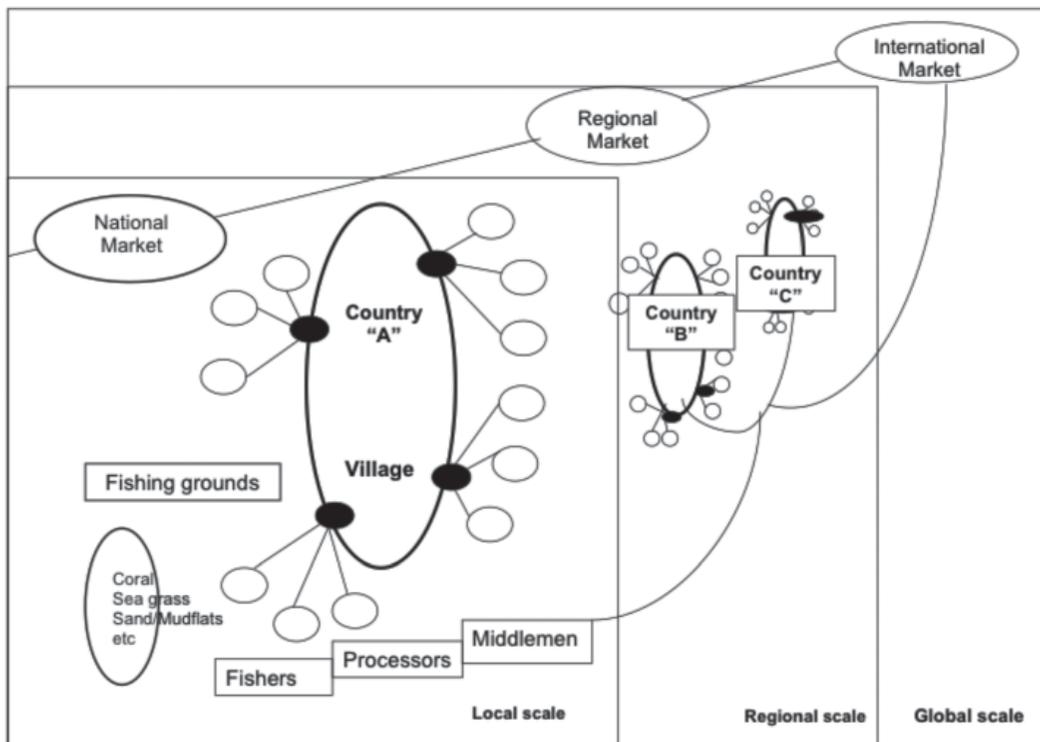


Figure 1. A conceptual model of the movement of sea cucumbers from the local to the global market (modified from de la Torre-Castro *et al* 2007).

This model allowed for elucidation of the linkages from the local fishing village to the international market, the number of links between the different elements of the fishery, and other information such as the distances and links between different places and stakeholders and the degree of cluster formation between stakeholders associated with the fishery. When populated with information derived from the interviews and other secondary sources, the model provided a broader understanding of the complexity of the sea cucumber fishery and where and what kinds of management interventions were effective within each country.

Fisheries management information

Apart from the information collected on fisheries management in the interviews and questionnaires, other material including policy documents, copies of regulations and gazette notices and information that identified historic and current legislation and management interventions was reviewed. Catch monitoring was also carried out at major sea cucumber landing beaches, once the main fishing season was identified from the interviews. This included the species and number of individual sea cucumbers collected, the number and type of gear and mode of fishing, the species, and an estimate of the fishing effort based on the number of fishers and the time spent fishing sea cucumbers. The length and weight of the dominant commercial species were measured to estimate the percentage of the catch below the size at sexual maturity. Export trade information was collected from fishing authorities or customs departments in the various countries and data that was collated by Conand (2008 in Toral-Granda *et al.* 2008) for 1994 to 2008 from the FAO Fishery Information Data and Statistics Unit database (FAO 2010). The awareness and perception of fishers, traders and management authorities were also assessed from the interviews as well as fisher livelihood options.

RESEARCH FINDINGS

The following results summarize the findings of the studies that were carried out during the Regional sea cucumber project. Since many of the individual studies have been published elsewhere, only the key findings are summarised below and referenced where appropriate. Included are also findings from other studies that were linked to the regional project, a socioeconomic and fisheries study in Mozambique by C. Macamo (Macamo 2009) and on the reproduction of *Holothuria leucospilota* in Kenya by J. Kawaka (Kawaka 2009) funded through the Marine Research Grant (MARG) II program of the Western Indian Ocean Marine Science Association. In addition, results of studies by students and partners that were associated with the project including J-M. Andriatsimalona, A. Burgos, H. Eriksson, S. Gaudron, S. Kohler, T. Lavitra, C. Macamo, T. Mmbaga, H. Nilsson, L. Nordlund, P. Odhiambo, S. Rakotomahefa, C. Raymond, Y. Razafimandimby and D. Taddei are also included for comparative purposes.

Ecological Studies

Species inventories

Comprehensive species inventories were undertaken during ecological surveys in Kenya and Reunion, species data were also collected in Madagascar, Mozambique, Tanzania mainland and Zanzibar during the fisheries surveys. In Kenya inventories were carried out from north to south in Mayungu, Malindi, Watamu, Kilifi, Vipingo, Kanamai, Mombasa, Tiwi, Diani, Shimoni using the timed searches. Surveys were conducted in shallow lagoons, sea grass beds, reef flats and reef edges. Only one additional species that was recorded in Kanamai and tentatively identified as *Holothuria coluber* but that could also be *H. flavomaculata* (C. Conand pers. comm.) was reported. Further taxonomic work will have to be carried out to verify this identification. Hence 45 species from 10 genera were recorded for Kenya. The cumulative number of species in the timed searches from 178 surveys in 14 locations (all searches pooled) including timed

searches from previous studies on the Kenyan coast (Muthiga 1997 - 2002 unpublished data) reached an asymptote after 160 minutes (**Fig. 2**).

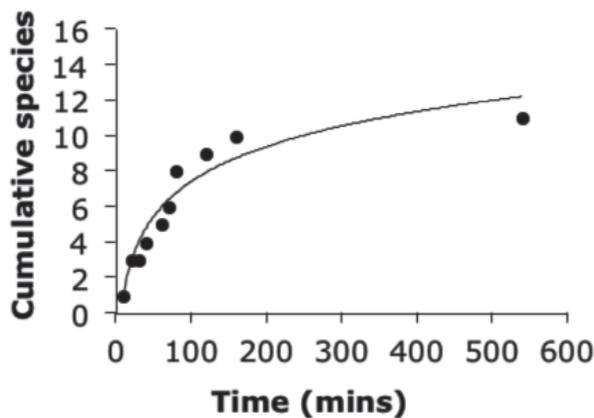


Figure 2. Cumulative species curve of sea cucumber species recorded during timed searches at 14 locations and 188 sites on Kenyan shallow reef habitats.

In Reunion, most of the surveys were conducted on the western side of the Island between La Possession and St Philippe. Eighteen new species records were reported which brings the total for Reunion to 37 species and 17 genera (Conand *et al.* 2010). However, a specimen tentatively identified as *Actinopyga obesa* is under further taxonomic investigation. In the Seychelles *Holothuria (Microthele)* sp. pentard from previous surveys is still under taxonomic investigation.

No new records were reported for Madagascar, Mozambique or Tanzania although several specimens of the genera *Holothuria* and *Stichopus* that were collected from Madagascar still need identification. The sea cucumber fauna of Mozambique and Tanzania that have very long coastlines and patch reefs were not as comprehensively surveyed as Kenya and Reunion.

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Overall, the order Aspidochirotida had the highest number of species, there were very few species from the Apodida and Dendrochirotida and Madagascar remains the most speciose with 125 species (**Table 1**).

Table 1. The diversity of sea cucumbers in some countries in the western Indian Ocean.

Country	No of species	Main taxonomic references	Comment
Kenya	10 genera 44 species	Humphreys 1981 Muthiga & Ndirangu 2000 Samyn 2003	<i>Holothuria arenacava</i> a new species not reported elsewhere in the WIO. <i>Holothuria coluber</i> a new record under further taxonomic investigation
La Reunion	17 genera 37 species	Conand 2003 Rowe & Massin 2006 Conand et al 2009 Conand et al 2010	<i>Actinopyga capillata</i> a new species, also reported in Rodrigues. 18 species are new records for Reunion
Madagascar	125 species	Cherbonnier 1988; Massin et al 1999 Rasolofonirina 2007	<i>Holothuria naso</i> , <i>Holothuria notabilis</i> and <i>Stichopus horrens</i> are new records while <i>Bohadschia atra</i> is a new species found in several countries in the WIO
Seychelles	125 species	Clark 1984 Aumeeruddy & Conand 2008	<i>Holothuria (Microthele) sp.</i> Pentard is still under taxonomic investigation
Tanzania mainland and Zanzibar	23 species (Pemba Is) 26 species reported in the catch	Samyn 2003 Eriksson 2010	Limited taxonomic work has been carried out in Tanzania mainland; Zanzibar has been surveyed more intensely

Abundance and distribution

Studies on the abundance and distribution of sea cucumbers were carried out in Kenya (Odhiambo 2007; Orwa *et al.* 2009), Madagascar (Razafimandimby 2008), Reunion (Burgos & Hollinger 2007) and Zanzibar (Eriksson 2010; *et al* 2010).

In Kenya, surveys were conducted from north to south at fringing reef sites in Malindi, Mayungu, Watamu, Wesa, Kivulini, Vipingo, Mombasa, Tiwi, Diani and Shimoni. Inner lagoons, reef flats and seagrass habitats 2 to 5m deep were surveyed between 2005 and 2007. Benthic substrate cover and topographic complexity were measured at each site and the density, relative abundance, species richness and diversity of sea cucumbers were determined in 100m/4m belt transects and one-hour times searches. A total of 12 species were recorded in 93 belt transects and 11 species in 36 hours of timed searches. Of these the most abundant recorded in both the belt-transects and time counts were *H. atra*, *H. leucospilota* and *S. chloronotus* that ranged between 1.08 to 1.25 indiv.400m². Other common species that occurred in smaller numbers included *Actinopyga mauritiana*, *Bohadschia subrubra* and *B. atra* in descending order of abundance (Table 2).

Table 2. The density (mean \pm SEM) and relative abundance of sea cucumber species in reefs in southern Kenya.

Scientific name	Common name	Commercial value	Mean density (ind.400m ²)	Relative Abundance %
<i>Actinopyga mauritiana</i>	Yellow surfish	Medium	0.11 \pm 0.04	2.74
<i>Actinopyga miliaris</i>	Blackfish	Medium	0.03 \pm 0.02	0.82
<i>Bohadschia atra</i>	Tigerfish	Medium	0.06 \pm 0.03	1.64
<i>Bohadschia subrubra</i>		Medium	0.10 \pm 0.04	2.47
<i>Holothuria atra</i>	Lollyfish	Low	1.25 \pm 0.22	31.78
<i>Holothuria hilla</i>		None	0.02 \pm 0.02	0.55
<i>Holothuria impatiens</i>		Low	0.04 \pm 0.03	1.10
<i>Holothuria leucospilota</i>		Low	1.25 \pm 0.22	30.68
<i>Holothuria pervicax</i>		None	0.02 \pm 0.02	0.55
<i>Stichopus chloronotus</i>	Greenfish	Medium	1.08 \pm 0.45	27.40
<i>Stichopus hermanni</i>	Curryfish	Medium	0.01 \pm 0.01	0.27

Source modified from Odhiambo 2007.

The overall density of sea cucumbers was variable and averaged 0.37 ± 0.06 ind.400m² (n = 93 transects) and ranged from 0.08 to 3.17 ind.400m². The average abundance of individual species was also relatively low; *H. atra* averaged 1.25 ± 0.22 ind.400m², *H. leucospilota* 1.25 ± 0.22 ind.400 m² and *S. chloronotus* 1.08 ± 0.45 ind.400m². On average, reef lagoons had significantly higher densities and diversity of sea cucumbers (5.5 ± 1.07 ind.400 m²; 11 species respectively) than reef flat (3.14 ± 0.72 ind.400 m²; 7 species respectively) habitats. Individual species varied in their distribution, while *S. chloronotus* and *S. maculata* dominated in lagoon sites, *H. atra* and *H. leucospilota* dominated in reef flat habitats. Only species of medium to low commercial value were encountered in the survey. There was a positive relationship between species richness and the number of individuals encountered, and species richness and the duration spent on sampling ($r = 0.78$, n = 12, p = 0.005 and $r = 0.73$, n = 14, p = 0.005 respectively).

Benthic substrate in the studied sites was composed of mainly algal turf (43%) and hard coral (15%), while seagrass, fleshy algae and sand composed < 10% of the substrate. Hard coral cover showed significant and positive correlation with sea cucumber density ($r = 0.79$), abundance ($r = 0.80$) and distribution ($r = 0.40$) but not with diversity. Calcareous algae and sponge on the other hand were weakly and negatively correlated with these parameters. The topographic complexity also differed between sites and was positively correlated with hard coral cover and sea cucumber abundances.

In Madagascar the study focused at sites in three locations Norinkazo, Beankiho and Mareana in Toliara bay southwest Madagascar. The sites were adjacent to Ankilibe village that had an active sea cucumber fishery. The sites at Norinkazo and Beankiho had similar sandy/muddy benthic substrate but differed in depth; Norinkazo was a sand bar that was exposed during spring low tides while Beankiho was permanently immersed to ~1.25m depth. The third location Mareana was a fringing reef site exposed to a relatively strong current and turbid waters. Surveys were carried out using 50m/2m belt transects laid perpendicular to shore. Sea cucumbers were censused while walking during spring tides at Norinkazo and while snorkeling at Beankiho and Mareana. All individuals that were encountered were collected, their length and wet weight were measured and the abundance, biomass and dominance were calculated. A

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total of 22 species of sea cucumbers were recorded (Table 3), two species *Holothuria* sp1 and *Holothuria* sp2 could not be identified in the field and are undergoing taxonomic verification.

Table 3. The sea cucumber species encountered at three locations Norinkazo, Beankiho and Mareana in Toliara Bay SW Madagascar

Species name	Local name
Family: Holothuriidae	
<i>Actinopyga echinites</i> (Jaeger, 1833)	Tronkena
<i>Actinopyga miliaris</i> (Quoy Gaimard, 1833)	Tronkenam-bato
<i>Actinopyga lecanora</i> (Jaeger, 1833)	Zangam-bato
<i>Bohadschia marmorata</i> (Jaeger, 1833)	Bemangovitra
<i>Bohadschia vitiensis</i> (Semper, 1868)	Falalijaka mavo
<i>Holothuria arenicola</i> (Semper, 1868)	Tsimihoke
<i>Holothuria atra</i> (Jaeger, 1833)	Stylo mainty
<i>Holothuria edulis</i> (Lesson, 1830)	Stylo, dorilisy mena
<i>Holothuria excellens</i> (Ludwig, 1875)	Delave
<i>Holothuria fuscogilva</i> (Cherbonnier, 1986)	Zanga benono
<i>Holothuria impatiens</i> (Forsk., 1775)	Stylo
<i>Holothuria leucospilota</i> (Brandt, 1835)	Stylo
<i>Holothuria notabilis</i> (Pearson, 1913)	Dorilisy, Tsimihoke
<i>Holothuria scabra</i> (Jaeger, 1833)	Zanga foty
<i>H. scabra versicolor</i> (Conand, 1986)*	Zanga mena
<i>Holothuria</i> sp1	Zanga eva
<i>Holothuria</i> sp2	Dorilisy lahy
Family Stichopodidae	
<i>Thelenota ananas</i> (Jaeger, 1833)	Borosy, rasta
<i>Stichopus chloronotus</i> (Brandt, 1835)	Maintsokely, zanga sono
<i>Stichopus horrens</i> (Selenka, 1867)	Jomelipapa, Crampon
<i>Stichopus naso</i>	Smerf
<i>Stichopus hermanni</i> (Semper, 1868)	Trakitera

Source modified from Razafimandimby 2008. **H. scabra vesicolor* is now named *H. lessoni* (Massin et al. 2009).

The abundance of individual species was highly variable ranging from 13 to 333 ind.ha⁻¹ (Table 4) and averaging 32.4 ± 9.7 ind.ha⁻¹ (mean ± SEM). *Holothuria arenicola* and *H. notabilis* were the most abundant at the sandy/muddy sites of Norinkazo and Beankiho, composing more than 78% of the sea cucumbers encountered. *Holothuria edulis*, *H. atra* and *S. horrens* (30%, 15% and 10% in order of dominance) were the most abundant at the coral reef site, Mareana. In general, there were on average higher densities of sea cucumbers in the sandy/muddy sites (40.2 ± 13.9 ind.ha⁻¹) than at the coral reef site (16.0 ± 5.4 ind.ha⁻¹). Sea cucumbers of high commercial value such as *H. scabra* were recorded in relatively low abundances at Norinkazo (17 ind.ha⁻¹) and Beankiho (67 ind.ha⁻¹). The biomass of individual species was also highly variable ranging from 1.25 to 27.5 ind.ha⁻¹ (Table 4) and coincided with the densities, being on average higher at the sandy-muddy sites (4.6 ± 1.4 kg.ha⁻¹) than at the coral reef sites (2.9 ± 1.0 kg.ha⁻¹). The sea cucumbers with the highest biomasses included *H. notabilis* and *H. arenicola* at Norinkazo and Beankiho.

Table 4. The density (#/ha) and biomass (kg/ha) of sea cucumbers at studied sites in SW Madagascar. The relative density and biomass are shown in brackets.

Species	Norinkazo		Beankiho		Mareana	
	Density (#/ha)	Biomass (kg/ha)	Density (#/ha)	Biomass (kg/ha)	Density (#/ha)	Biomass (kg/ha)
<i>A. echinites</i>	0 (0)	0 (0)	0 (0)	0 (0)	25 (10)	4.3 (9.5)
<i>A. lecanora</i>	0 (0)	0 (0)	0 (0)	0 (0)	13 (5)	4.4 (9.5)
<i>B. vitiensis</i>	0 (0)	0 (0)	17 (2.9)	2.50 (3.3)	13 (5)	1.9 (4.1)
<i>H. atra</i>	17 (2.4)	2.50 (3.5)	33 (5.7)	5 (6.7)	38 (15)	5.6 (12.2)
<i>H. edulis</i>	0 (0)	0 (0)	17 (2.9)	4.17 (5.6)	75 (30)	9.4 (20.2)
<i>H. excellens</i>	0 (0)	0 (0)	0 (0)	0 (0)	13 (5)	2.50 (5.4)
<i>H. leucospilota</i>	17 (2.4)	1.67 (2.4)	33 (5.7)	5.83 (7.8)	13 (5)	1.25 (2.7)
<i>H. notabilis</i>	217 (31)	27.50 (38.8)	183 (31.4)	24.1 (32.2)	0 (0)	0 (0)
<i>H. scabra</i>	17 (2.4)	3.33 (4.7)	67 (11.4)	18.3 (24.4)	0 (0)	0 (0)
<i>H. lessoni</i>	0 (0)	0 (0)	17 (2.9)	4.2 (5.6)	0 (0)	0 (0)
<i>H. arenicola</i>	333 (47.6)	26.67 (37.7)	0 (0)	0 (0)	0 (0)	0 (0)
<i>Holothuria sp1</i>	50 (7.1)	2.50 (3.5)	200 (34.3)	8.3 (11.1)	0 (0)	0 (0)
<i>Holothuria sp2</i>	17 (2.4)	3.33 (4.7)	0 (0)	2.5 (3.3)	0 (0)	0 (0)
<i>H. impatiens</i>	33 (4.8)	3.33 (4.7)	17 (2.9)	0 (0)	0 (0)	0 (0)
<i>S. horrens</i>	0 (0)	0 (0)	0 (0)	0 (0)	50 (20)	14.4 (31)
<i>S. naso</i>	0 (0)	0 (0)	0 (0)	0 (0)	12.5 (5)	2.5 (5.4)

Source modified from Razafimandimby 2008.

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The surveys in Reunion were conducted in the summer of 2007 and the factors that control sea cucumber distribution and abundance at five reefs (St. Gilles, La Saline, St. Leu, Etang Salé and St. Pierre) were also evaluated. Measurements of density, species richness, biomass, grain size, total organic matter and benthic substrate were taken at a total of 10 sites in inner reef flats and back reefs habitats. Twenty-one species were recorded during the surveys; *H. atra* and *H. leucospilota* dominated while *A. echinites*, *A. mauritiana*, *B. vitiensis*, *S. chloronotus* and *Synapta maculata* were very common.

The overall average density of sea cucumbers (mean \pm SD) was 88.6 ± 141.7 ind.100m⁻² ranging from site averages of 0.7 ± 0.1 ind.100m⁻² (Saint-Pierre south) to 683.3 ± 96.6 ind.100m⁻² (Planch'Alizé). Three species, *H. atra*, *H. leucospilota* and *S. chloronotus* (Table 5) had the highest densities and when combined composed ~90% of the total abundance. The latter was particularly abundant and dominated in the back reef habitats of Etang Salé (203.7 ± 2.5 ind.100m⁻²) and Grand Trou d'eau (210 ± 45.8 ind.100m⁻²). The biomass of the dominant species *H. leucospilota* and *H. atra* was highest in the inner reef flat habitats especially La Saline and St Gilles where they reached a biomass of up to 3098 and ~ 1992 g wet weight.100m⁻² (respectively), and densities of 136.7 ± 47.8 and 510 ± 99.3 ind.100m⁻² (respectively). Local spatial variability was also high on these reefs.

Table 5. The density (mean \pm SD) and relative abundance of sea cucumbers on Reunion Island

Scientific name	Common name	Commercial value	Mean abundance (ind.100m ²)	Relative abundance %
<i>Actinopyga echinites</i>	Deep water redfish	Medium	2.9 \pm 5.9	3.4
<i>Actinopyga mauritiana</i>	Yellow surfish	Medium	1.3 \pm 2.4	1.5
<i>Bohadschia vitiensis</i>	Brown sandfish	Low	0.3 \pm 1.3	0.4
<i>Holothuria atra</i>	Lollyfish	Low	25.6 \pm 1.1.8	30.6
<i>Holothuria leucospilota</i>		Low	25.0 \pm 0.22	30.0
<i>Stichopus chloronotus</i>	Greenfish	Medium	25.2 \pm 59.1	30.2
<i>Synapta maculata</i>		Medium	7.2 \pm 7.2	3.6
Other species			<0.1	<0.1

Source modified from P. Frouin pers. comm.

The five reefs surveyed in Reunion had a medium to coarse grain size with less than 4% total organic matter although the variability within reefs was greater than between reefs with significant differences in grain size between the inner reef flat and back reef habitats. Overall, the study found no correlation between sea cucumber distribution and factors such as chlorophyll a and grain size at the whole Island scale (BioEnv test, $r < 0.1$ for each variable) but significant differences at the individual reef scale. For example, at La Saline reef that is over 2km long, the distribution of the main sea cucumber species could be explained by chlorophyll a concentration in the sediments (BioEnv test, $r = 0.538$). Individual species also had variable responses to geomorphological factors with *B. vitiensis*, *H. atra* and *S. chloronotus* preferring back reef areas, *A. echinites* and *A. mauritiana* preferred reef flats while *H. leucospilota* and *S. maculata* occurred in both habitats.

The abundance and distribution data available for Zanzibar is summarized from stock assessments of commercial sea cucumbers. The surveys were conducted by visual census at depths of 0.5 to 8m using line transects and manta tows at three villages, Mkokotoni on the north-western side, Uroa on the eastern side and Fumba on the south-western side of Unguja Island. These sites were selected due to the presence of an active sea cucumber fishery. A total of fifteen species were recorded in 269 manta tows and 258 line transects ranging from 0.1 to 37 ind.ha⁻¹. The dominant species

included *H. edulis*, *Pearsonothuria graeffei*, *H. atra* and *H. leucospilota* in decreasing order of abundance. Species of high commercial value such as *H. fuscogilva* and *H. scabra* occurred in very low densities (0.11 ± 0.1 and 1.74 ± 1.7 ind. ha^{-1} respectively). The distribution of sea cucumbers varied with habitat and although *H. atra* was found in relatively higher abundances at all habitats, *P. graeffei* and *H. edulis* preferred reef to lagoon or soft bottom habitats while *H. leucospilota* tended to prefer lagoon and soft bottom to reef habitats.

Recruitment surveys

A few observations of recruits of sea cucumbers were recorded in the field during the project. For example, juveniles of *Actinopyga echinites* (9-10 cm) were observed in seagrass beds at Saint Gilles (Reunion) in December 2007 (Kohler et al. 2009) (Fig. 3). In Kenya, juveniles and small individuals of *S. chloronotus* (6.5 - 7.5 cm) were observed in June, August, and October 2008, individuals of *H. atra* (8 - 10 cm) were observed in August, November and December while *Bohadschia atra* (14 cm) were observed in August and October 2008 (Muthiga unpublished data). All the reports from Kenya were recorded in the sandy patches between coral heads in reef lagoons or under rocks and boulders on reef flats.



Figure 3. Juveniles of *Actinopyga echinites* in seagrass beds in Reunion (photo P. Bourjon).

Marine protected area effectiveness

The study on the differences between protected (no-take) and fished sites was conducted in Kenya between 2005 and 2007 (Odhiambo 2007; Orwa *et al.* 2009). Information was also available comparing abundances and species in the Chumbe Is. Coral Park (no-take) Zanzibar and adjacent fished reefs (Eriksson *et al.* 2010). Four main locations were surveyed in Kenya that had protected parks adjacent to fished sites, Malindi, Watamu, Mombasa and Shimoni. Protected reefs on average had significantly higher ($p < 0.5$) densities of sea cucumbers than fished reefs (Fig. 4a) but there was no significant difference in diversity between these management categories (8 and 9 species for parks and fished sites respectively). Overall, reef lagoons also had significantly higher densities and diversities than reef flat habitats regardless of management category (Fig. 4b) and diversity was also moderately higher in reef lagoons (11 species) than in reef flats (7 species).

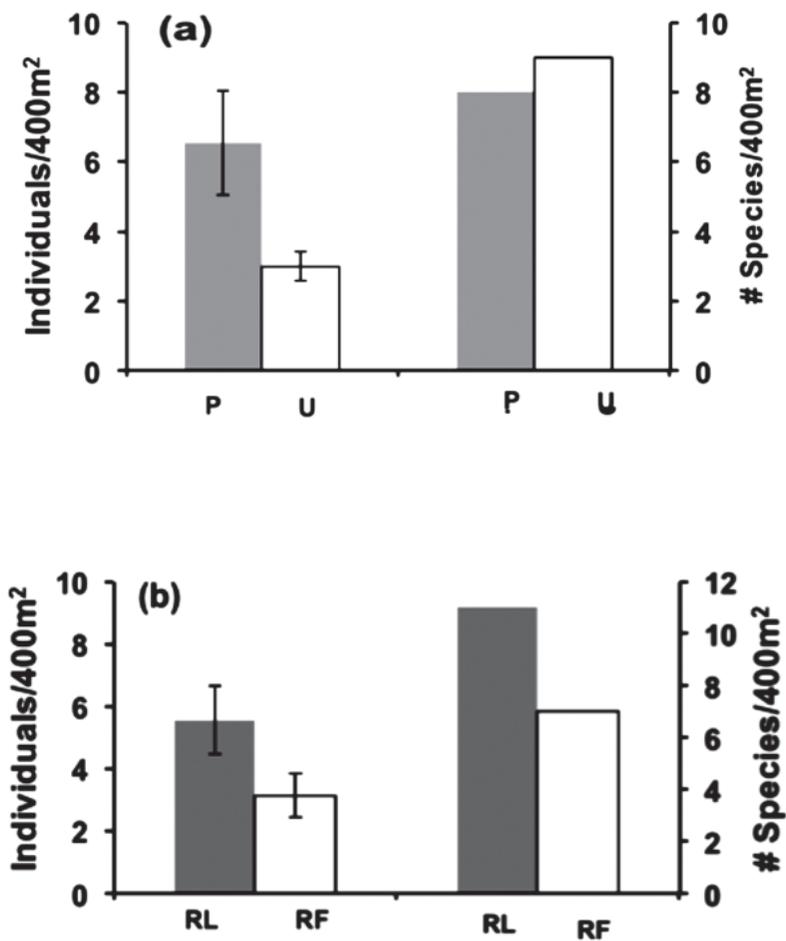


Figure 4. Comparison between sea cucumber abundances (left bars) and number of species (right bars) at sites under different management regimes (protected vs. unprotected (a) and in different habitats (reef lagoons vs. reef flats (b)).

Densities were especially high in protected reef lagoons (8.52 ± 2.32 ind.400m⁻²) than in protected reef flats (4.17 ± 1.52 ind.400m⁻²) but there was no significant difference between abundances of sea cucumbers in fished lagoons and fished reef flats (2.07 ± 0.28 and 2.04 ± 0.47 ind.400m⁻² respectively). Of the four locations studied, Mombasa and Kisite marine parks had the highest densities of sea cucumbers (15 and 12 ind.400m⁻² respectively). A higher diversity of sea cucumbers was also recorded at the Chumbe Is Coral Park than at the adjacent fished reefs Ukombe and Kwale on Unguja Is. Zanzibar. While cumulative species curves showed a levelling off at the fished reefs in Unguja, the curve was steeper for the Chumbe Is. site. The study also reported 10 times higher abundances of *B. atra* a species of medium commercial value at Chumbe Is. than at the fished sites.

Biological Studies

The studies on reproduction focused on *A. echinites* and *H. leucospilota* in Reunion; *H. fuscogilva* and *H. scabra* in Kenya; *H. notabilis*, and *S. horrens* in Madagascar; and *H. scabra* in Tanzania. The studies evaluated when these species reproduced, the environmental factors that affected reproduction and measured key life history characteristics such as sex ratio, size at sexual maturity and reproductive output that are useful for developing management interventions. The studies were undertaken at different times in the different countries (Table 6). The following are the key findings of the studies that were carried out in Kenya (Kawaka 2009; Muthiga & Kawaka 2009; Muthiga *et al.* 2009), in Reunion (Kohler 2006; Gaudron *et al.* 2008; Kohler *et al.* 2009), Master thesis research studies in Madagascar (Razafimandimby 2008) and PhD research in Tanzania (Kithakeni pers. comm.).

Table 6. The locations, species, year of study and average sea surface temperatures (SST) of the study sites in the western Indian Ocean. The mean annual SST is calculated from NOAA data (8-year mean monthly) for Kenya, Madagascar and Tanzania and Conand *et al.* 2007 for Reunion period.

Country	Location	Latitude	Species	Year	SST
Kenya	Shimoni	4° S	<i>Holothuria fuscogilva</i>	2006 - 2007	27.5
Kenya	Vanga	4° S	<i>Holothuria scabra</i>	2006 - 2007	27.7
Tanzania	Buyuni	6° S	<i>Holothuria scabra</i>	2006 - 2007	27.6
Tanzania	Kunduchi	6° S	<i>Holothuria scabra</i>	2006 - 2007	27.6
La Reunion	La Saline	21° S	<i>Actinopyga echinites</i>	2005 - 2006	26.1
La Reunion	La Saline	21° S	<i>Holothuria leucospilota</i>	2005 - 2006	26.1
Madagascar	Toliara bay	23° S	<i>Holothuria notabilis</i>	2006 - 2007	26.6
Madagascar	Toliara bay	23° S	<i>Stichopus horrens</i>	2006 - 2007	26.6

Morphological characteristics

The sea cucumber species varied in morphological characteristics. *Holothuria fuscogilva* and *H. notabilis* were the largest and smallest (respectively) in terms of length, total weight and gutted weight (Table 7). The gutted weight was significantly correlated to the total weight and to the length in all the studied species. The weights of the guts that were only measured in *H. fuscogilva* and *H. scabra* comprised on average $15.7 \pm 1.6\%$ ($n = 96$) and $33.7 \pm 1.6\%$ ($n = 215$) of gutted weight (respectively) in these species. This gut index showed no significant difference between females and males in both species.

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Table 7. Morphological characteristics of sea cucumber species measured as the overall average (\pm SEM) length (mm), total body weight (g), gutted weight (g) and gut weight (g). Correlations between the length and the gutted weight, and the total weight and gutted weight of individuals are also provided.

Morphology	<i>H. notabilis</i>	<i>A. echinites</i>	<i>H. leucospilota</i>	<i>H. scabra</i>	<i>S. horrens</i>	<i>H. fuscogilva</i>
Body length (mm)	181.6 \pm 2.9 (248)		254 \pm 0.24 (439)	244.4 \pm 10.7 (518)	236.5 \pm 3.2 (269)	379.6 \pm 3.6 (341)
Total Body weight (g)	183.5 \pm 5.4 (265)		198.5 \pm 3.94 (428)	263 \pm 7.0 (695)	353.3 \pm 8.1 (299)	1614.7 \pm 17.3 (595)
Gutted weight (g)	46.54 \pm 0.9 (337)	107.0 \pm 3.3 (160)	118.9 \pm 2.1 (251)	186 \pm 6.7 (761)	224.3 \pm 4.3 (334)	1329.0 \pm 14.5 (595)
Gut weights (g)				69.9 \pm 0.3 (759)		213.7 \pm 3.5 (593)
Comparisons						
Length vs. gutted weight	r = 0.821 (182) ***			r = 0.69 (304) ***	r = 0.65 (271) ***	r = 0.47 (161) ***
Total weight vs. gutted weight	r = 0.67 (199) ***	r = 0.88 (155) ***	r = 0.70 (235) ***	r = 0.91 (304) ***	r = 0.93 (334) ***	r = 0.91 (161) ***

Levels of significance are indicated as * = 0.05, ** = 0.01, *** = 0.005. The sample size is shown in brackets. Source modified from Razafimandim by 2008; Gaudron *et al* 2009; Kohler *et al.* 2009; Muthiga & Kawaka 2009; Muthiga *et al.* 2009.

The mode of reproduction was sexual for all the studied species and the sexes did not differ significantly in morphological characteristics except in the Reunion populations, where females of *A. echinites* and *H. leucospilota* had significantly higher body weights than males; the males of *H. leucospilota* were on average only three quarters of the weight of females.

Annual reproductive cycles

The relationship between the gonad index and the size of individual sea cucumbers is an important indicator of reproductive state in some sea cucumbers. This relationship was tested by calculating the correlation between the body size (measured as gutted weight) and gonad index for *H. fuscogilva* and *H. scabra* in Kenya. There was no significant relationship between gonad index and body size for either species ($r = 0.04$, $n = 567$; 0.18 , $n = 254$ respectively). In the study of *H. scabra* at Buyuni and Kunduchi (Tanzania) where the gonad index was estimated using total body weight and not gutted weight, a weak but negative relationship was found between total body weight and gonad index ($r = -0.68$, $n = 80$, $p = 0.01$). A correlation between the average monthly gonad indices of females and males also showed a high level of synchrony between the sexes of *H. fuscogilva* (0.87 ; $p = 0.005$; $n = 12$) and *H. scabra* (0.79 ; $p = 0.005$; $n = 12$) in Kenya.

The pattern of reproduction measured as the changes in the average monthly gonad indices displayed differences between the species. Four of the studied species showed biannual reproduction that also differed in the onset of gametogenesis and spawning in individual species. In Kenya, *H. scabra* showed a major peak in gonad index in October (9%) and a minor peak between April and June (4 - 5%), spawning occurred between July and September and again in

December - January. *Holothuria fuscogilva* on the other hand, had a major peak in gonad indices in July - September (6 - 7%) with a minor peak in January - February (4%), and an extended spawning period from October to December and again between March - April. In Reunion, *H. leucospilota* and *A. echinites* also showed a biannual pattern of reproduction with two spawning periods. *Actinopyga echinites* had the highest gonad indices in November (> 20%) and spawning occurred immediately after in December - January with a second minor spawning in April. In *H. leucospilota* on the other hand, gonad indices peaked in January (> 40%) and in April (35%) and spawning occurred in February and again in May. Two species *H. notabilis* and *S. horrens* showed a distinct annual pattern of reproduction with one spawning period differing only in the onset of gametogenesis and spawning (Fig. 5). Gonad growth commenced in May - July in *H. notabilis* and July - September in *S. horrens*, and peaked in October in *H. notabilis* (38%) and November (8%) in *S. horrens*. Spawning occurred between November - December in *H. notabilis* and January - March in *S. horrens*. The monthly gonad indices of both of these species were highly correlated for the two years sampled ($r = 0.78, p = 0.025$ and $r = 0.6, p = 0.05$ respectively).

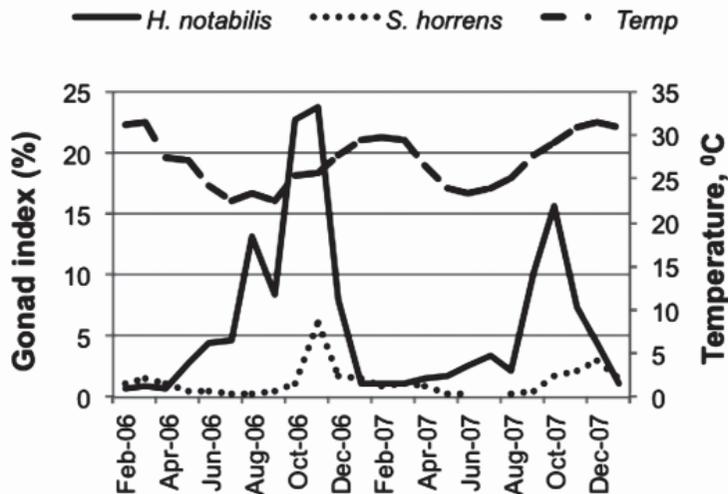


Figure 5. The seasonal pattern of reproduction of the sea cucumbers *Holothuria notabilis* and *Stichopus horrens* from SW Madagascar. Source modified from Razafimandimby 2008. Gonad maturity stages

In addition to the gonad index method, histological analysis was also carried out on all the species studied except *H. fuscogilva* and *H. scabra* in Kenya. The results provided a finer resolution to the interpretation of the onset of gametogenesis and spawning. Histological preparations of individuals in monthly sample were classified into five maturity stages and the gonads of the studied species showed similar general characteristics. Resting (I) and immature (II) stage gonads were translucent to white and often could not be distinguished between the sexes. Growing (III) gonads had variable tubule size and colour ranging from creamy white in males with sperm starting to accumulate in the tubule lumen and pale rose in females with oocytes of different sizes accumulating in the tubule lumen. Mature (IV) gonads had the longest tubules and were deep red in females and beige in males and the lumen were full of the largest sized oocytes or mature sperm (respectively). At the post spawning (V) stage, the gonads were translucent

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in males and rose to translucent in females with relic sperm or oocytes (respectively) and the tubules showed signs of disintegration (Fig. 6).

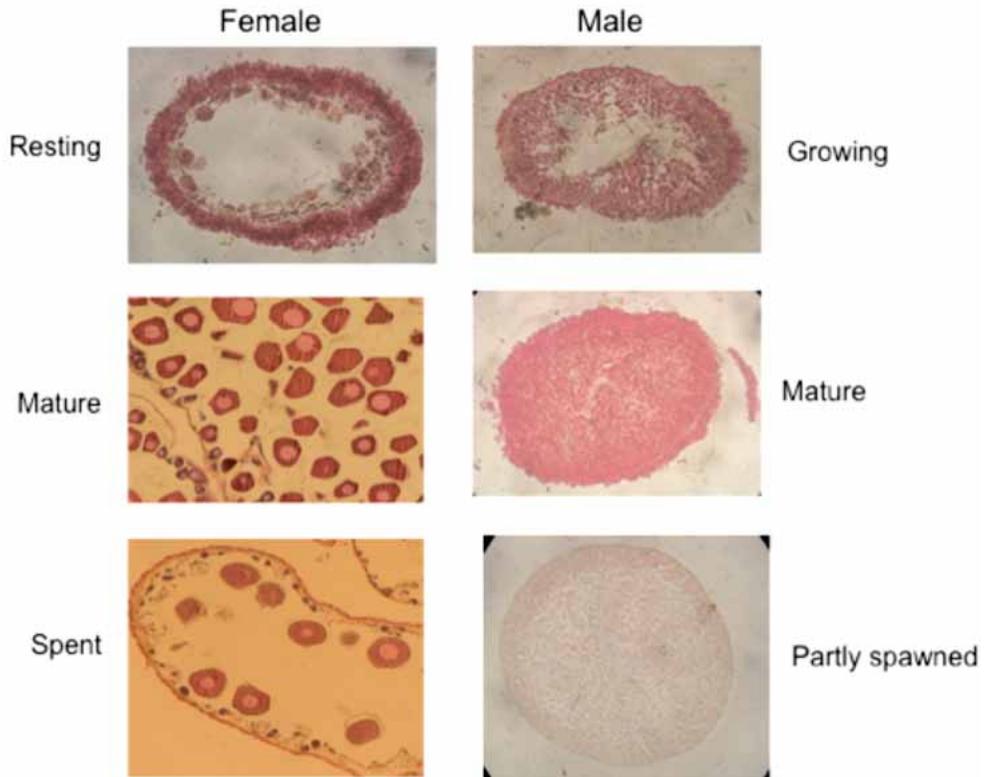
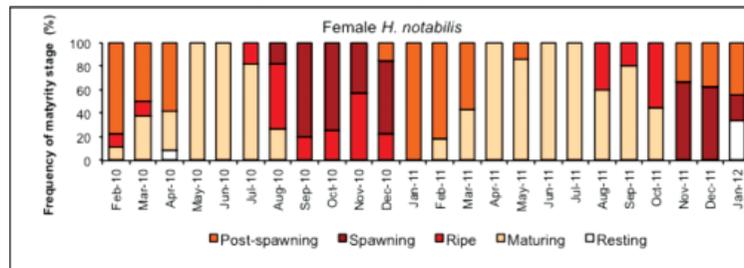
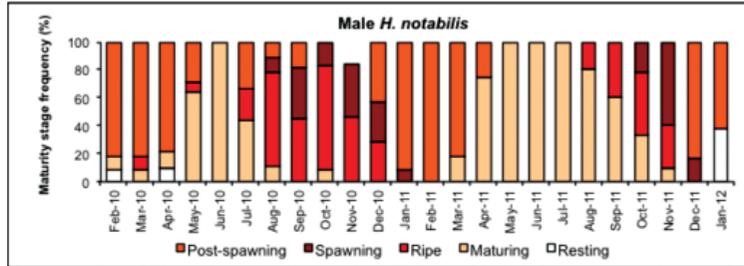


Figure 6. Micrograph of maturity stages of female and male gonads of *Holothuria notabilis* from SW Madagascar. Source modified from Razafimandimby 2008.

a) *H. notabilis*



b) *S. horrens*

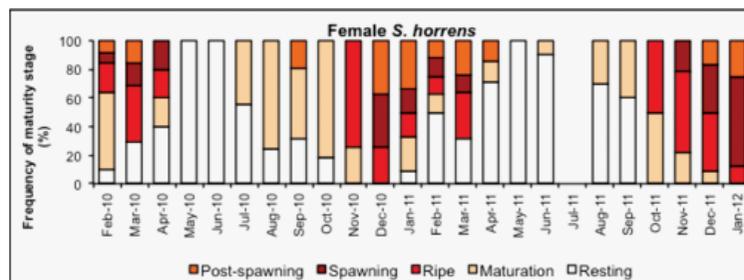
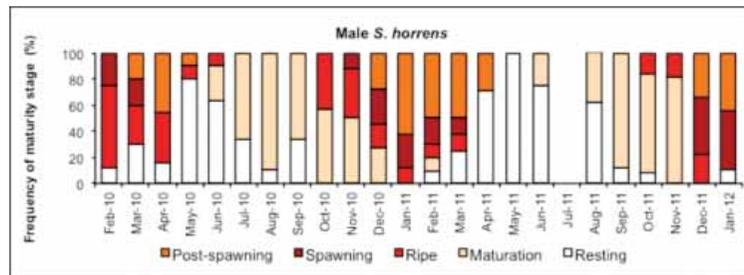


Figure 7. Frequency histograms of the sexual maturity stages of *Holothuria notabilis* (a) and *Stichopus horrens* (b) in Toliara Madagascar. Source modified from Razafimandimby 2008.

A similar correspondence between the frequency of maturity stages was recorded for *S. horrens* (Fig. 7b), *A. echinites* and *H. leucospilota*. In *H. scabra* in Tanzania, mature stages were present throughout the year but gonad indices peaked from May to August in Buyuni and January to May in Kunduchi.

Sex ratio and size at sexual maturity.

The sex ratio for the different species varied, in Kenya, both *H. fuscogilva* and *H. scabra* had significantly more males than females when all data regardless of year were pooled. The sex ratio of *H. scabra* populations at Buyuni and Kunduchi (Tanzania) also had significantly more males than females. In Reunion, both *A. echinites* and *H. leucospilota* populations had significantly more females than males (Table 8). The sex ratio was particularly skewed in the *H. leucospilota* population at La Saline (Reunion), where females constituted more than 90% of the samples. In Madagascar, *H. notabilis* and *S. horrens* had sex ratios that were not significantly different from unity.

When data from previous studies in Kenya (Muthiga & Ndirangu 2000) were compared with the current study, results showed a shift in sex ratio from unity. In *H. fuscogilva* the sex ratio was at unity between the period 1998-1999 and 2001-2002 ($\chi^2 = 0.41$; $df = 196$, and $\chi^2 = 0.17$; $df = 142$ respectively) and shifted to significantly more males (113) than females (82) in the 2006 - 2007 samples ($\chi^2 = 4.93$; $df = 194$; $p = 0.05$). The sex ratio also shifted from unity to more males in *H. scabra* ($\chi^2 = 36$; $df = 163$; $p = 0.005$) in the same time period.

Table 8. The sex ratio and size (g) at sexual maturity of sea cucumbers in the western Indian Ocean. Deviation of the sex ratio from unity was tested with the Chi-squared test. The size at sexual maturity is estimated for the total weight and the gutted weight (in brackets*).

Location	Species	Sex ratio (F:M)	Size at sexual maturity (g)
Shimoni (Kenya)	<i>Holothuria fuscogilva</i>	82:113; $\chi^2 = 4.93$, $p = 0.05$	1167
Vanga (Kenya)	<i>Holothuria scabra</i>	64:100; $\chi^2 = 36.0$, $p = 0.005$	22.6
Buyuni (Tanzania)	<i>Holothuria scabra</i>	64:109; $\chi^2 = 0.34$, $p > 0.05$	
Kunduchi (Tanzania)	<i>Holothuria scabra</i>	33:100; $\chi^2 = 0.47$, $p = 0.005$	
La Saline (Reunion)	<i>Actinopyga echinites</i>	2:1; $\chi^2 = 15.7$ (46 - 55)* $p < 0.001$	65 (46-55)
La Saline (Reunion)	<i>Holothuria leucospilota</i>	191:17; $\chi^2 = 72.8$, $p < 0.001$	180 (51 - 75)*
Toliara (Madagascar)	<i>Holothuria notabilis</i>	152:164; ns	63 (20)*
Toliara (Madagascar)	<i>Stichopus horrens</i>	155:139; ns	254 (170)*

*Data are for mature gonads only.

Two methods were used to estimate the size at sexual maturity. In the Kenya studies, a proxy measure of size at sexual maturity was estimated for *H. fuscogilva* and *H. scabra* as no histology was done for these species. This consisted of averaging the gutted weight of the smallest sized individuals with stage 3 - 5 gonads using macroscopic observations of the gonads recorded during the peak reproductive period. With this method, the size at sexual maturity for *H. fuscogilva* was 1167g and for *H. scabra*, it was 22.6g (gutted weight)..

The second measure of size at sexual maturity was more rigorous and used a method based on microscopic observation of the gonads, described by Conand (1993). For each individual of a species, the gutted weight was measured, the gonads were processed for histological examination and the frequency of individuals undergoing gametogenesis based on pooling gonads in stage III to IV was plotted. The size at which 50% of the sample was undergoing gametogenesis indicated the size at sexual maturity. Using this method the size at sexual maturity *A. echinites* was 50.5 g and 63g for *H. leucospilota* in Reunion, and 20g for *H. notabilis* and 170g for *S. horrens* in Madagascar (Fig. 8).

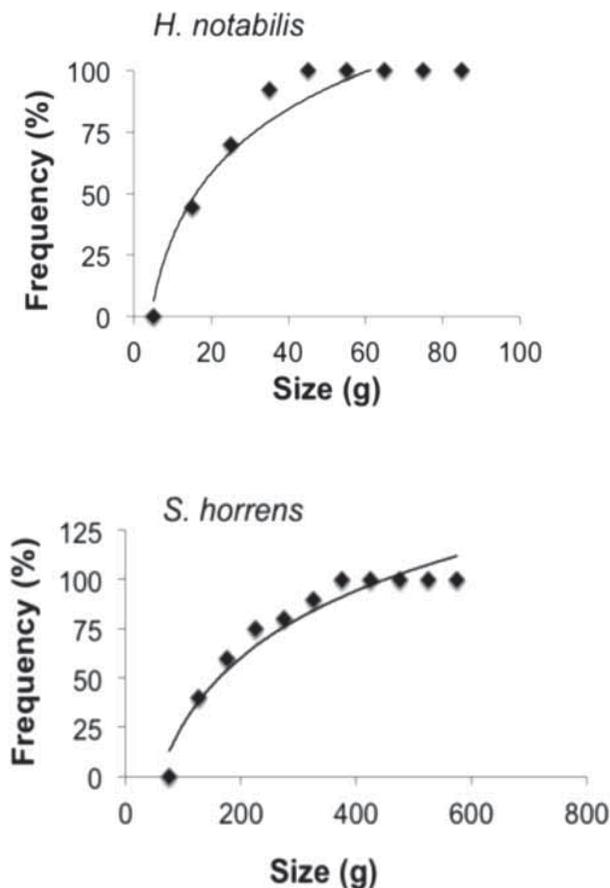


Figure 8. Size at sexual maturity for *Holothuria notabilis* and *Stichopus horrens* from SW Madagascar measured as the size (eviscerated weight g) at which 50% of the sample was undergoing gametogenesis. Source modified from Razafimandimby 2008

Reproductive output

The reproductive output was estimated using different parameters; (1) the gonad size measured as gonad wet weight (g) and the tubule length (mm), (2) the gonad size relative to body size (Gonad index%) and (3) the fecundity (number of oocytes per female). Fecundity was estimated from July to December for *H. fuscogilva* and October to December for *H. scabra* during the peak reproductive period for these species in Kenya.

There was significant variability in the reproductive output within the species and amongst the species. For example, although *H. fuscogilva* the largest sized sea cucumber, had on average the largest gonads (75 g), the smallest gonads were recorded in *H. scabra* the third heaviest of the studied species. Within the species however, gonad size had a positive relationship with body size. *Holothuria notabilis* had the highest gonad index at 25.6 % of gutted weight and *H. fuscogilva* and *H. scabra* had the lowest gonad indices (Table 9).

There was also variation in the reproductive output between the sexes of the different species. Females had higher gonad weights than males in all but *A. echinites* with highly significant differences occurring in *H. fuscogilva* and *H. leucospilota* (Table 9). The gonad indices of female *H. fuscogilva* and *H. leucospilota* were also statistically significantly higher than males as were the gonads of female *H. scabra* but this was not statistically significant. None of the other studied species showed significant differences in the average gonad indices between females and males.

Table 9. Comparison of (a) the reproductive output of females and males measured as the average gonad wet weight (g) and (b) the reproductive output relative to individual size of females and males measured as gonad index for different sea cucumber species

a) Gonad weight (g)				
Species	Females	Males	Overall	P
<i>A. echinites</i>	13.6 ± 1.3 (94)	11.1 ± 1.6 (47)	12.8 ± 1.0	0.247 ns
<i>H. leucospilota</i>	24.8 ± 2.0 (191)	12.2 ± 2.0 (17)	23.7 ± 1.8	0.05
<i>H. fuscogilva</i>	95.41 ± 5.14 (250)	63.36 ± 3.36 (285)	75.70 ± 2.98	0.001
<i>H. scabra</i>	11.7 ± 0.83 (259)	10.4 ± 0.70 (317)	9.27 ± 0.47	0.14 ns
<i>H. notabilis</i>	14.21 ± 12.54 (26)	9.02 ± 5.58 (46)		
<i>S. horrens</i>	15.02 ± 17.26 (20)	7.31 ± 3.65 (30)		
b) Gonad index (%)				
Species	Females	Males	Overall	P
<i>A. echinites</i>	11.9 ± 1.0 (94)	11.9 ± 1.5 (47)	11.9 ± 0.9	0.991 ns
<i>H. leucospilota</i>	20.1 ± 1.4 (191)	13.2 ± 1.9 (17)	19.5 ± 1.3	0.12
<i>H. fuscogilva</i>	6.19 ± 0.33 (250)	3.85 ± 0.19 (285)	4.77 ± 0.19	0.001
<i>H. scabra</i>	5.52 ± 0.41 (254)	4.71 ± 0.31 (311)	4.99 ± 0.38	0.14 ns
<i>H. notabilis</i>			25.6 ± 12.5	
<i>S. horrens</i>			6.19 ± 9.5	

Source modified from Kohler 2006; Gaudron *et al* 2009; Kohler *et al* 2009; Muthiga & Kawaka 2009; Muthiga *et al* 2009; Razafimandimby 2008.

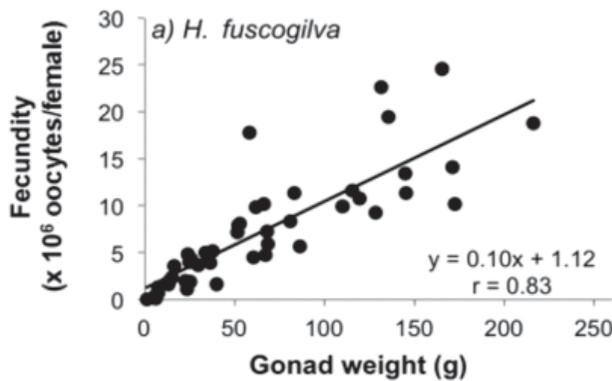
Holothuria leucospilota had the longest tubules (~128mm) almost three times longer than *H. scabra* (~ 50mm) that had the shortest tubules (Table 10).

Table 10. The reproductive output of sea cucumbers measured as the mean (\pm sem) tubule length (mm) for males and females (pooled), and fecundity ($\times 10^6$ oocytes/female) for females.

Species	Tubule length (mm)	Fecundity ($\times 10^6$ oocytes/female)
<i>H. fuscogilva</i>	119.3 \pm 10.0 (45)	9.1 \pm 1.1 (32)
<i>H. scabra</i>	49.0 \pm 6.5 (31)	1.0 \pm 0.4 (25)
<i>A. echinites</i>	51.6 \pm 1.8 (160)	
<i>H. leucospilota</i>	127.8 \pm 4.7 (208)	
<i>H. notabilis</i>	91.7 \pm 28.5 (72)	
<i>S. horrens</i>	74.0 \pm 24.3 (50)	

Although within the species, larger individuals had longer tubules, there was no relationship when compared across species. Since fecundity using the direct oocyte count method was only measured in *H. fuscogilva* and *H. scabra* in Kenya, the relationships between fecundity and other measures of reproductive output could only be done for these two species. *Holothuria fuscogilva* produced an overall average of $6.45 \pm 0.88 \times 10^6$ oocytes/female and an average of $9.1 \pm 1.1 \times 10^6$ oocytes/female between July-December at the peak of gonad production. Whereas *H. scabra* had a lower fecundity producing an average of $0.78 \pm 0.2 \times 10^6$ oocytes/female and of $1.0 \pm 0.4 \times 10^6$ oocytes/female during its peak reproductive period (Table 10). In Tanzania, *H. scabra* collected from Kunduchi averaged 5.21×10^6 oocytes/female and 1.13×10^6 oocytes/female at Buyuni. In general, there was a positive relationship between tubule length and individual body size and gonad weight in these species.

The number of oocytes contained in the gonad of *H. fuscogilva* and *H. scabra* was dependent on the size of the gonad (Fig. 9 a, b) since there was a significant and positive relationship between the size of the gonad (wet weight) and fecundity in both species.



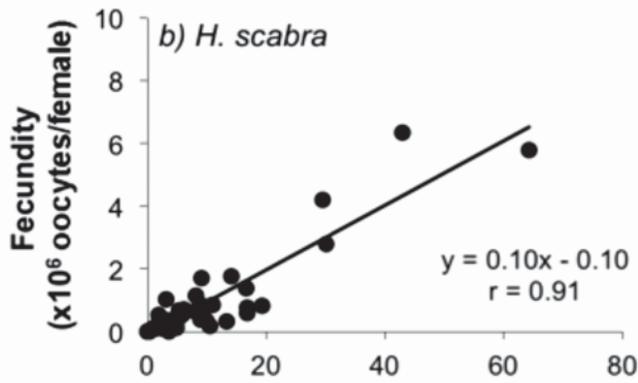
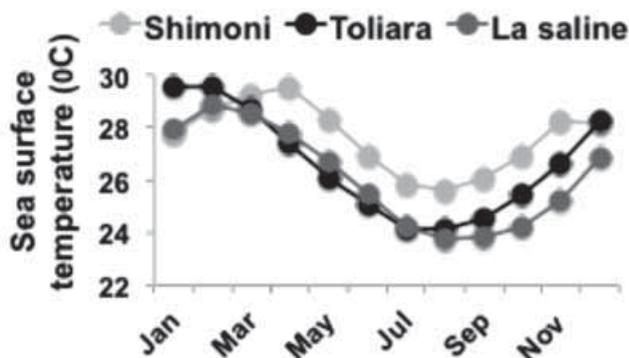


Figure 9. The relationship between the gonad weight (g) and fecundity (oocytes x10⁶/female) for *Holothuria fuscogilva* (a) and *H. scabra* (b) collected on southern Kenyan reefs.

The other measure of gonad size, the gonad tubule length, also showed a positive and significant relationship with the number of oocytes present in the gonad in *H. fuscogilva* ($r = 0.32$; $n = 39$, $p < 0.05$), and although a similar relationship was found for *H. scabra*, the number of samples were not sufficient to evaluate statistical significance.

Environmental factors

Sea surface temperature and light showed a seasonal pattern in the countries sampled with SST peaking between January - February in Toliara, February - March in Reunion and March - April in Kenya . Light also showed a seasonal pattern that peaked with SST but that decreased a month earlier than SST and started rising a month earlier in Kenya (Fig.10). In Reunion, light peaked in September - December before the peak in SST and started increasing in May when SST had started to decrease. Rainfall peaked in April-May in Kenya, December to February in Madagascar and February-March in Reunion.



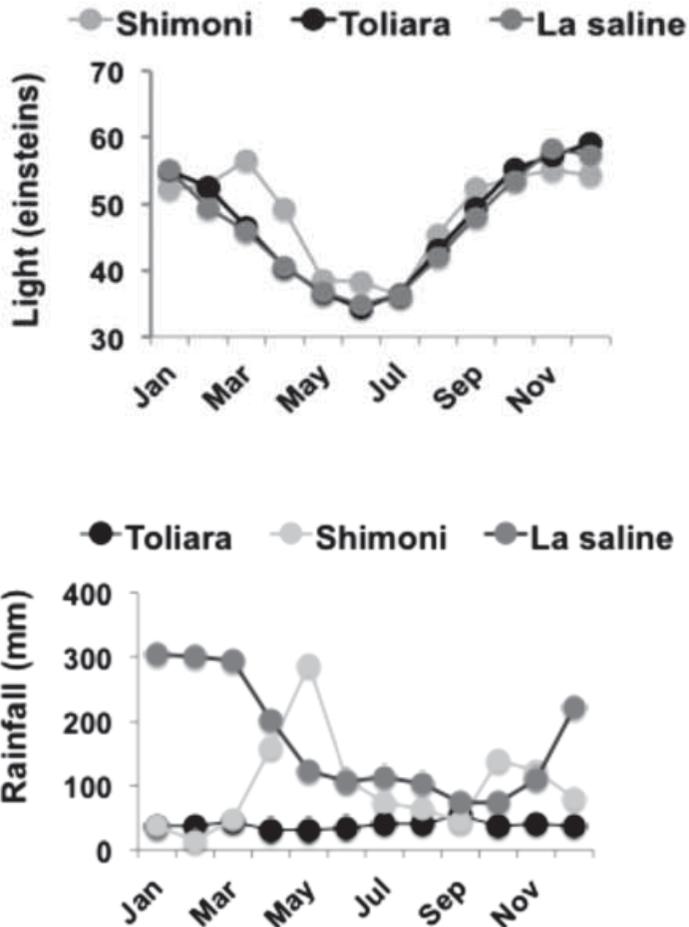


Figure 10. The sea surface temperature, light and rainfall at La saline (Reunion), Shimoni (Kenya) and Toliara (Madagascar).

The correlations between mean monthly changes in the gonad indices of the different sea cucumber species and environmental parameters showed varying responses and did not depend on the species or location (Table 11). Three of the six species *H. fuscogilva* and *H. scabra* in Kenya, and *H. leucospilota* in Reunion showed a correlation between gonad index and SST with *H. fuscogilva* showing the strongest relationship. Four species showed a significant relationship between gonad index and light including *H. scabra* in Kenya, *A. echinites* and *H. leucospilota* in Reunion, and *S. horrens* in Madagascar. The strongest relationships between gonad index and light were exhibited by *H. scabra* and *A. echinites*. None of the species studied showed a correlation between gonad index and rainfall.

Table 11. Correlations between mean monthly gonad indices and sea surface temperature (°C), light (einsteins) and rainfall (mm) of different species of sea cucumbers.

Location	Species	Lat	SST (°C)	Light (MJ/m ² /day)	Rainfall (mm)
Shimoni	<i>H. fuscogilva</i>	4°S	r = 0.87***	r = 20 ns	r = 0.35 ns
Vanga	<i>H. scabra</i>	4°S	r = 0.59*	r = 0.82***	r = 0.41 ns
La Saline	<i>A. echinites</i>	21°S	r = 0.11 ns	r = 0.75**	r = 0.23 ns
La Saline	<i>H. leucospilota</i>	21°S	r = 0.59*	r = 0.55*	r = 0.05 ns
Toliara bay	<i>H. notabilis</i>	23°S	r = 0.43 ns	r = 0.46 ns	r = 0.33 ns
Toliara bay	<i>S. horrens</i>	23°S	r = 0.41 ns	r = 0.73 ***	r = 0.39 ns

Significance level * = 0.05, ** = 0.01; *** = 0.005. Source modified from Gaudron *et al* 2008; Razafimandimby 2008; Kohler *et al.* 2009; Muthiga & Kawaka 2009; Muthiga *et al.* 2009.

Only *H. fuscogilva* and *H. scabra* collected in Kenya were tested for the influence of lunar periodicity that was measured by correlating gonad index with lunar day during the peak reproductive period. Gonad indices of *H. fuscogilva* during this period showed a significant but weak relationship with lunar day (r = 0.41; p = 0.01; n = 12) with the highest gonad indices occurring in the first quarter of the moon and the lowest in the last quarter of the moon. There was no relationship between lunar day and gonad index in *H. scabra* (r = 0.24; n = 16).

Socioeconomics and fisheries management

The studies on the socioeconomics and fisheries management of sea cucumbers focused on: 1) describing the socioeconomic conditions of sea cucumber fishers; 2) evaluating the status and general characteristics of the fishery; and 3) describing the management of the fishery (de la Torre-Castro *et al.* 2007). The following summarizes the findings from each of these components from the studies that were conducted during the project. These include studies on the south coast of Kenya (Ochiewo *et al.* 2010), student research studies in Zanzibar (Nilsson 2008; Nordlund 2008; Raymond 2008), and Madagascar (Andriatsimalona 2007; Rakotomahéfa 2007; Razafimandimby 2008), a socioeconomic survey conducted in the Seychelles (Pinault & Conand 2007), and a review of the fishery in the Seychelles (Aumeeruddy 2007; Aumeeruddy & Conand 2008). In addition, other studies that partnered with the project include a brief survey of the fishery in Mozambique (Macamo 2009); PhD research conducted in Zanzibar by H. Eriksson (Eriksson 2010; Eriksson *et al.* 2010); and an FAO update of the fisheries trends in countries of the Indian Ocean (Conand 2008).

Socioeconomic characteristics of sea cucumber fisher communities

Since the socioeconomic characteristics of the sea cucumber fishery are less well understood throughout the region, the project focused on detailed studies in Kenya, Madagascar and Zanzibar. Results of brief surveys conducted in Mozambique and the Seychelles are also presented.

In Kenya, more than 132 respondents focusing on sea cucumber fishers, first level middlemen based at the collection villages and second level middlemen and exporters who were based in Mombasa (the administrative headquarters of the Kenyan coast) were interviewed. More than 70% of the catch of sea cucumbers was reported in the south coast (Kwale district) in Vanga, Majoreni, Shimoni and Gazi where harvesting of sea cucumbers was an important component of daily fishing activities. The fishery was artisanal and concentrated in intertidal (43%) and subtidal (47%) habitats

depending on the geomorphology of the area. For example, fishers in Kiromo and Kibuyuni (Shimoni area) collected intertidal species while fishers from Vanga and the main villages in Shimoni free dived in waters 3 to 5 m deep. Fishing was mainly carried out in the northeast monsoon season when the seas were calm and waters less turbulent using canoes (57%), wooden planked sailboats (18%), motorboats (15%) and outriggers (10%).

Results also showed that all the sea cucumber fishers in Kenya were men, 73% were married and a high percentage of the respondents were household heads responsible for an average of seven dependents (Table 12). More than 50% of collectors were aged between 19 - 30 years, 42% were between 31 and 50 years and only 5% were older than 50 years. Most fishers had no (22%) or a very low level of education averaging 4.9 years primary education while only 8% had higher education and a few years attendance in religious schools (Madrassa).

Table 12. The demographic structure of sea cucumber fishers in Kenya, Madagascar, Seychelles and Zanzibar. The educational level was based on the average number of school years attended and the household size corresponded to the number of dependents.

Characteristic	Kenya	Madagascar	Seychelles	Zanzibar
Age (yrs)	(19 - 40)			34 (14 - 66)
Sex (%)				
Male	100	60.5	100	71
Female	0	13	0	29
Children	0	26.5	0	0
Marital status (%)				
Married	71.7	-	70	68.5
Single	16.7	-	-	25
Other	11.7	-	-	6.5
Household size	7.3	-	3 - 4	6
Educational level				
Primary	66.7	-	100	41
Secondary	8.3	-	100	44
College	-	-	-	1
Other	3.9	-	-	7

Source modified from Pinault & Conand 2007; Nilsson 2008; Ochiemo *et al.* 2010.

Sea cucumbers in the western Indian Ocean

Improving management of an important but poorly understood resource

Although sea cucumber fishers also harvested other products, a high percentage in the studied villages depended solely on sea cucumbers for their livelihoods (~70%). Other sources of livelihood included fishing finfish, lobsters and octopi, casual employment and subsistence farming. Fishing occurred mainly in the calm northeast monsoons and farming and casual employment occurred during the much rougher southeast monsoons. Although the income earned by sea cucumber fishers was not measured, a rough estimate was calculated from the catch per unit effort (CPUE) and price. The CPUE for fishers at the studied villages averaged 6 to 21 sea cucumbers/man/day. This was estimated to provide 60 to 210 KES/man/day (~0.7 - 2.5 USD/man/day) for low grade and 1200 to 4200 KES /man/day (~14 - 50 USD/man/day) for high grade sea cucumbers.



Figure 11. Children collecting sea cucumbers in Madagascar. (photo M. Pinault)

In Madagascar, sea cucumber fishing evolved from a traditional form of gleaning for subsistence to a more formal artisanal fishery using gleaning, snorkeling and skin-diving in relatively shallow waters (> 1m). The fishery was often familial with all members of the family involved (Fig. 11). An illegal fishery using SCUBA and motorised boats that stay for long periods at sea and that fish in deeper waters was also occurred. The surveys in Madagascar were concentrated on the west coast where sea cucumber fishing has been carried out for decades as a traditional form of fishing mainly in the south-west Toliara region. Interviews were conducted in 12 villages (Table 13) where a total of 280 fishers and 30 collectors were interviewed from August 2006 to January 2007 (Andriatsimialona 2007; Rakotomahéfa 2007) and from March to September 2007 (Razafimandimby 2008). The number of fishers was highest at Morombe, Anakao and

Ankilibe, villages that also tended to have the highest number of inhabitants. Exporters were based at Morombe and Besakoa.

Table 13. The number of fishermen, collectors and exporters in twelve villages in Toliara Madagascar.

Surveyed Villages	Population	Fishermen	VillageCollectors	Exporters
Morombe	4926	1830	9	3
Andavadoaka	1220	807*	6	
Salary Nord	1452	515	11	
Andrevo	2975	258	5	
Ifaty	600	390	7	
Besakoa	1074	137	2	3**
Ankiembe	1981	300	4	
Ankilibe	2863	1076	2-4	
Sarodrano	1624	392	2	
Anakao	3983	1623	5	
Beheloka	1044	192	4	
Androka	653	346	3	

* Source Blue Ventures 2006; ** Exporters based in Besakoa and Ankiembe

Results showed that only a few collectors limited their harvesting to sea cucumbers; fish, octopi, bivalves, sea urchins and crustaceans were also collected for commercial and subsistence purposes. Harvesting of sea cucumbers was carried out by men, women and children and depended on the proximity to the collection grounds and the state of the tides. The main vessels that were used to access the barrier reef were the traditional dugout canoes. At Ankilibe village where the survey was conducted during both spring and neap tides, men (51%), women (26%) and children (23%) collected sea cucumbers during the spring tides (Table 14). During neap tides however, only men (70%) and children (30%) collected sea cucumbers. Tides also affected the biomass of sea cucumbers harvested for example, at Ankilibe village, the catch averaged $44,900 \pm 4,009$ pieces/month ($3,109 \pm 550$ kg/month wet weight) during the spring tides, and $21,990 \pm 3,905$ pieces/month ($1,715 \pm 326$ kg/month) during the neap tides.

Table 14. The variation in numbers of harvesters during spring and neap tides in Ankilibe village (Toliara Madagascar) from August 2006 to January 2007.

Month	Spring Tide			Neap Tide		
	Men	Women	Children	Men	Women	Children
August-06	467	205	219	229	0	92
September-06	516	276	219	271	0	111
October-06	557	256	222	418	0	198
November-06	491	241	227	441	0	199
December-06	561	311	261	494	0	205
January-06	384	163	152	349	0	147
Percent (%)	51	26	23	70	0	30

Source modified from Andriatsimalona 2007; Rakotomahefa 2007.

Sea cucumbers in the western Indian Ocean

Improving management of an important but poorly understood resource

Fishing effort measured as catch per unit effort (kg/fisher/hr) did not differ between tides (0.82 ± 0.03 and 0.96 ± 0.05 for spring and neap tides respectively) at Ankilibe, but fishing effort measured as fisher hours during spring tides, was more than twice (273 ± 11.8 fisher hours) that of neap tides (113 ± 11.3 fisher hours). Fishing effort was also estimated by recording the catch at ten villages for a period of 15 days. A total of 40,353 sea cucumbers were collected during this period and there was significant variability in the production between villages and between species (Table 15). The highest production was recorded at Sarodrano village that contributed 20% of the overall combined catches, followed by Andrevo (15%) and the lowest harvest was recorded at Ifaty and Andavadoaka. The catch was skewed towards *H. notabilis* that contributed 60% of the overall catch while *S. horrens* was a distant second at 10.5%.

Table 15 Fishing effort measured as the total numbers of sea cucumbers collected in 10 villages in Toliara Madagascar for 15 days in each village between March and September 2007.

Species	Morombe	Andavadoaka	Salary nord	Andrevo 1	Andrevo 2	Ifaty	Ankiembe	Ankilibe	Sarodrano	Anakao
<i>A. echinites</i>	435	21	966		903	4		40	205	132
<i>A. lecanora</i>	31		116							
<i>A. mauritiana</i>	69	7	319		140			141		30
<i>B. vitiensis</i>							23	64	151	
<i>H. atra</i>	140		57		1679		12	11		336
<i>H. fuscogilva</i>	22		126	364						115
<i>H. notabilis</i>	1830			3768	3372	488	3163	3130	6086	2205
<i>H. leucospilota</i>					17	3				1863
<i>H. nobilis</i>	44	2								
<i>H. scabra</i>	311	10		792	84		335	493	295	
<i>H. lessoni</i>	62	1				11	88	103	119	
<i>S. horrens</i>	469	32	346	1204	104	12		324	1115	634
<i>S. hermanni</i>	109			8	14	1				28
<i>H. excellens</i>						7				
<i>Others</i>						153		153	153	153
<i>Total harvest</i>	3522	73	1930	6136	6313	679	3621	4459	8124	5496
<i>Percentage</i>	8.73	0.18	4.78	15.2	15.6	1.7	9.0	11.0	20.1	13.6

Source modified from Andriatsimalona 2007; Rakotomahefa 2007.

The sea cucumber fishers in Madagascar the lowest levels of education, about 55% of respondents never went to school, 40% attended primary school and only 5% attended secondary school (Table 12). All the surveyed villages only had primary schools. Households consisted of 5 to 6 people on average with 3 to 4 children.

The study in Zanzibar focused on eight locations (Chwaka, Fumba, Mazizini, Mkokotoni, Mtende, Nungwi, Unguja and Uroa) on the main Island of Unguja where sea cucumber fishing was concentrated. A total of 105 sea cucumber fishers, processors, traders and beach recorders were interviewed. The fishery was similar to the Madagascar fishery in that men, women and to a very small extent children were involved (Table 12). The fishery was artisanal and carried out in different habitats depending on accessibility and mode of collection. Of the estimated 765 collectors, 43% were

women and 22% men who mainly collected in shallow intertidal areas close to shore. Collection by snorkelling (27%) and SCUBA (6.5%) was dominated by men and occurred in the subtidal and deeper areas (10 – 50m depth) that were accessed by wooden boats. Similar to the other countries in the region fishing was mainly carried out during the calmer northeast monsoon season.

The level of education of the sea cucumber fishers was on average slightly higher than in Kenya with 44% of the respondents having a secondary, 41% a primary, and 1% a college education, while 7% had some years of religious education (Table 12) and 7% never attended any formal educational facility. The age structure did not differ significantly from the Kenyan fishers, collectors ranged from 15 – 66 years and averaged 35 years for males and 32 years for females (34 years overall) and the processors ranged from (24 – 68) years and averaged 36 years. Very few women were involved in processing and trading sea cucumbers.

The study in Zanzibar also attempted to calculate the contribution of sea cucumber fishing to individual fisher incomes and to the village economy. Estimates from 17 villages indicated a total of 765 collectors, with a gross daily income ranging from 3200 TZS for collections close to shore that worked approximately 14 days per month, to 33,350 TZS for collectors using SCUBA that worked ~25 days per month. Fishers using SCUBA collected on average more sea cucumbers (TZS) (5.6 pieces/man/hour) than shoreline collectors (3.5 pieces/man/hour) or snorkelers (4.3 pieces/man/hour). The total gross income in the studied villages ranged from 5 to 255 million TZS per year and totalled 872m TZS (~753,000 USD) in 2008. Fishers that fished by gleaning and snorkeling earned 50% of fishers using SCUBA, who had a higher CPUE, and collected more of the higher value species than the other two groups. Processors also earned more on average than fishers – 9150 TZS per day if only processing and 6650 TZS per day if processing and collecting.

In Mozambique, the study focused on Inhassorro and Mozambique Is. that are key sea cucumber fishing grounds (Macamo 2008). Results showed that fishers were divided into three main groups. The group that fished in the intertidal areas was composed mainly of women and children who collected sea cucumbers opportunistically while gleaning for bivalves and sea urchins for subsistence during spring low tides. The second group composed of mainly youth and men, used sailboats and canoes to access deeper areas and used snorkelling gear. The last group also used snorkel gear and skin dived in waters 2.5 to 15m which were accessed by motorised boat. On average men composed 84% of all sea cucumber fishers on Mozambique Is. and 100% at Inhassoro. The average age of collectors was 29 for men, 24 for women on Mozambique Is. and 27 years at Inhassoro (Table 12). Fishing for sea cucumbers was an important activity for these fishers contributing ~87% of the household incomes. On average gleaners collected 1-2 animals to 1kg wet weight of sea cucumbers per day generating a gross income of 2 - 4 USD per day. Snorkelers and skin divers had higher catches (1 – 5kg; 50 - 100kg respectively) and consequently earned a higher gross income (4 - 19USD per day for the snorkelers).

The survey that was conducted in the Seychelles (Pinault & Conand 2007) was limited to interviews of 5 fishers based on Mahé Is. Results showed that the average age of fishers was similar to Kenya ~ 40 to 50 years, fishers were educated up to secondary school but not beyond, were married and had 2 – 3 children (Table 12). The socioeconomic condition of the sea cucumber fishers in the Seychelles was the highest of the studied countries. The fishers owned small (5-6m) or large (10-12m) motorised boats (Fig. 12) and navigation systems that allowed them to access distant offshore areas such as the Amiranthes banks and the St Pierre Plateau.



Figure 12. Fishing boats used for harvesting sea cucumbers in the Seychelles (photo C. Conand)

The survey also showed that different strategies were used to maximize earnings from the fishery. Smaller boats fished in inshore waters on the Mahé Plateau catching 300 to 400 high to medium value sea cucumbers per day. On the other hand, large boats fished offshore either in the Amirantes plateau (850km from Mahé Is.) or as far as the St Pierre plateau (1200km offshore). In these cases, boats stayed 6 to 20 days at sea during the main harvesting season (NW monsoon), caught 150 to 200 specimen per day dominated by the high value teatfish *Holothuria sp.* (pentard) and *H. fuscogilva*. The study estimated that the smaller boats had the most efficient strategy because of the smaller crew, lower operational costs and less need for expensive equipment, however, the larger boats and longer trips were favoured. It was estimated that the sea cucumber fishery employed about 100 people in the Seychelles who in general earned a monthly income that was higher than the national average.

Status and general characteristics of the sea cucumber fishery

The characteristics of the sea cucumber fishery from harvest to export (production chain) were studied using a generalized framework that showed the four levels of interaction (local, regional, national to international) described by Conand (2004a) and developed into a more detailed conceptual framework (Fig. 1) by the project socioeconomic team (de la Torre-Castro *et al.* 2007). The production chain varied in complexity at the different levels depending on the country. In south coast Kenya, on Unguja Is. Zanzibar, in Inhassoro and Mozambique Is. in Mozambique and in the

Seychelles, fishermen collected sea cucumbers and sold their catch to local middlemen located in their villages (termed 1st level middlemen in Kenya and processors in Zanzibar), or processors stationed in the main coastal ports such as on Mahé Is in the case of the Seychelles. The fresh product was then processed at this level by the middlemen/processors and either sold to 2nd level middlemen (Kenya) or to traders (Zanzibar) or directly to the international market as in the Seychelles. Sometimes the 2nd level middlemen in Kenya were skipped and the product was sold directly to exporters based in the major port town of Mombasa. In Zanzibar, the traders were equivalent to the exporters in Kenya.

The prices of both the fresh and processed products were set by the middlemen and traders and although it varied depending on the species and the landing beaches, fishermen had little negotiating power. The general flow of profits increased as the product moved up the value chain but the actual increase in profit throughout the production chain was difficult to estimate due to inadequate and unreliable information on sales and exports.

The system in Toliara Madagascar differed somewhat from the other countries. In this system, fishers had two main routes to the international market (Fig. 13). One route consisted of fishers that harvested sea cucumbers and sold them fresh to village collectors (equivalent to the 1st level middlemen in Kenya).

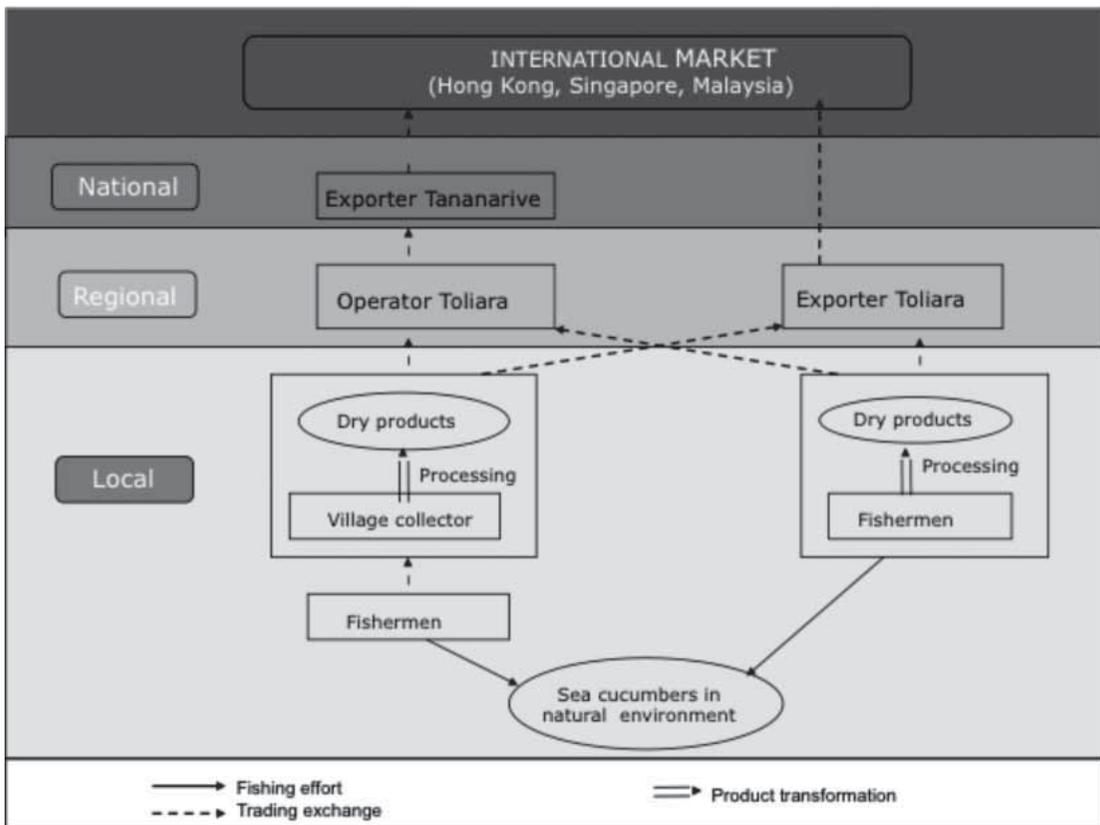


Figure 13. A generalized model of the movement of sea cucumbers in Madagascar from collection to the international market.

These collectors processed the fresh catch and subsequently sold the processed product to operators in Toliara (equivalent to the 2nd level middlemen in Kenya), who then sold the processed product to exporters from Antananarivo.

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Another route comprised fishers who harvested and processed the catch and sold to exporters in Toliara who then exported from the port direct to the international market.

The surveys at the studied sites showed that the harvest was composed of 11 species in the Kenyan south coast villages, 16 species in Madagascar, 21 species in Mozambique and 20 species in Zanzibar (Table 16). The composition of the catch varied however, for example, at the Kenyan sites, 95% of the catch in Majoreni village comprised the high value species *H. scabra* while a more diverse composition occurred in Shimoni (*H. scabra* 20%, *T. ananas* 17% and *H. nobilis* 17%). In the Madagascar villages, *H. notabilis* a low value species comprised 40 to 90% of the catch. In Zanzibar, 84% of the catch was composed of low value species including *H. atra*, *H. leucospilota*, *H. coluber*, *A. echinites*, *A. mauritiana*, and *A. lecanora*. The catch in the Seychelles was dominated by high value species: *H. fuscogilva*, *H. nobilis*, *Holothuria sp. (pentard)* and *T. ananas* that contributed ~90% of the catch. Other species included the medium value *A. mauritiana*, *A. echinites* and *A. miliaris*, and the low value species *H. atra*.

Table 16 The sea cucumber species collected in villages in the south coast of Kenya, in Toliara Madagascar, on Unguja Is. Zanzibar and on Mozambique Is. and Inhasoro in Mozambique.

Species	Value	Kenya	Madagascar	Mozambique	Zanzibar
<i>A. echinites</i>	Low	✓	✓	✓	
<i>A. lecanora</i>	Low	✓	✓	✓	✓
<i>A. mauritiana</i>	Medium	✓	✓	✓	✓
<i>A. miliaris</i>	Medium			✓	✓
<i>H. atra</i>	Low		✓	✓	✓
<i>H. edulis</i>	Low			✓	✓
<i>H. leucospilota</i>	Low		✓	✓	✓
<i>H. fuscogilva</i>	High	✓	✓	✓	✓
<i>H. fuscopunctata</i>	Medium			✓	✓
<i>H. nobilis</i>	High	✓	✓	✓	✓
<i>H. notabilis</i>	Low		✓	✓	
<i>H. scabra</i>	High	✓	✓	✓	✓
<i>H. lessoni</i>	High		✓		✓
<i>H. spinifera</i>	Low		✓		✓
<i>P. graeffei</i>	Low			✓	✓
<i>S. chloronatus</i>	Medium			✓	✓
<i>S. herrmanni</i>	Medium	✓	✓	✓	✓
<i>S. horrens</i>	Low		✓	✓	✓
<i>T. ananas</i>	High	✓	✓	✓	✓
<i>T. anax</i>	Medium	✓		✓	✓
<i>B. atra</i>	Low	✓			✓
<i>B. argus</i>			✓	✓	
<i>B. subrubra</i>	Low	✓		✓	
<i>B. vitiensis</i>	Low	✓	✓	✓	

Source modified from Andriatsimialona 2007; Rakotomahefa 2007; Macamo 2009; Nilsson 2008; Raymond 2008; Eriksson *et al.* 2010; Ochiwo *et al.* 2010.

Production trends

From the early 1990s, Madagascar, Kenya, and Tanzania provided yearly beche-de-mer production data to FAO and these were compiled by Conand from 1994 to 2004 in the regional review (Conand & Muthiga 2007) and updated for the FAO global review on fisheries and trade of sea cucumbers to 2005 (Conand 2008 in Toral-Grande *et al.* 2008). The production trends were recently updated again to 2008 (Table 17). The Seychelles which had the oldest records of sea cucumber production in the WIO dating from 1894 to 2004 (reported in Marguerite 2005) did not start reporting to FAO until 2006.

Table 17. Sea cucumber production in countries of FAO Area 51 (tonnes), Area 57, Indonesia and Sri Lanka and world production from 2004 to 2010.

Country	2004	2005	2006	2007	2008	2009	2010
Egypt	15	5	6	7	9	–	–
Madagascar	600	700	820	820	700	760	710
Maldives	546	351	264	339	252	159	627
Tanzania	10	14	<0.5	<0	0	0	0
Kenya	28	19	18	17	33	11	22
Yemen	230	130	32	11	11	10	10
Mozambique	1	ND	ND	ND	ND	ND	ND
Mauritius	ND	ND	340	620	95	100	100
Seychelles	129	243	319	372	285	487	448
Total area 51	1558	1462	1799	2179	1385	1527	1917
Indonesia	414	658	523	395	452	481	391
Sri Lanka	280	234	135	288	423	389	425
Total area 57	694	892	658	683	875	870	816
World total	16888	18668	19188	19972	19429	24170	24482

Source modified from Conand 2008 and FAO 2011 data.

In general, production decreased in most countries except the Seychelles. For example in Kenya where data were available from 1949, catches averaged less than 10 MT per year in the 1950s, increased tenfold in the 1970s-1990s to average 100 MT then declined to 23 MT by 2008. In Madagascar, the overall trepang production of the country declined from a high of 5400 MT between 1994 to 1997 to 701 MT in 2008, although the Ministère de la Pêche et des Ressources Halieutiques (M.P.R.H) reported 300 MT in 2009. Madagascar nevertheless remained the top exporter of trepang from the western Indian Ocean comprising 40% of the total production for FAO area 51 that encompasses most of the countries of the WIO and the Red Sea.

The production of beche-de-mer in Tanzania peaked at 1800 MT in 1998 and declined to 10MT by 2004 and to < 0.5 MT in 2008. Production data for Tanzania was complicated by the fact that different management regimes prevailed in Mainland Tanzania where a ban on sea cucumber harvesting was instituted in 2006, and Zanzibar where harvesting is currently legal. Production in Mozambique was also poorly monitored and FAO data shows very low production of 1 or less MT. Production of beche-de-mer in the Seychelles that has the longest trend series was low and averaged 13 MT between 1900s to 1980 and increased dramatically to average 295 MT between 1980 and 2004, and remained

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relatively stable averaging 448 MT by 2010. Within Area 51, the Maldives and the Seychelles showed relatively healthy sea cucumber fisheries with stable or increasing production trends. Compared to world production, Area 51 showed a decrease averaging 29.2% of world production between 1994 and 2004 to 7.8% in 2010.

Management of the sea cucumber fishery

The systems of management in the different countries including, the legislation, policies and regulations, and management interventions were reviewed and are described in detail in Conand & Muthiga (2007). Updates to the legislation and new strategies were also discussed during the final Regional Workshop on Sea Cucumbers of the Western Indian Ocean that was held in Mombasa (Muthiga *et al.* 2010).

The principal guiding legislation in most countries was the Fisheries Act upon which fisheries policies and regulations were based (Table 18). Fisheries were managed either by a Department, Division or Directorate under a Ministry of Fisheries (Kenya, Mozambique), a Ministry of Agriculture and Fisheries (Comoros, Mauritius) or Ministry of Environment and Natural Resources (Seychelles). In an effort to strengthen the management and development of fishing, there were strategies to replace Fisheries Departments/Divisions with semi-autonomous fishing authorities in some countries. This included the Seychelles Fisheries Authority that was established in 2002 and the Deep Sea Fishing Authority of Tanzania (amended regulations 2009). In Kenya, the new National Ocean and Fisheries Policy (2008) recommended the establishment of a Fisheries Service that would function like a parastatal with broader powers to collect and use revenue.

Licensing for the collection and trade of sea cucumbers was the primary management tool (Table 19), which occurred in all the countries except Reunion where sea cucumbers have never been exploited and in Tanzania (mainland) where a ban was in force. Closures in the form of MPAs were also present in most countries and although they were not established specifically for the protection of sea cucumbers, they protected species within their boundaries. Another form of closures, seasonal closures were only reported in Madagascar. Size limit regulations were reported in Madagascar, Mozambique and Zanzibar, while in Kenya, sea cucumber fishers were reported to voluntarily limit collection to no smaller than the length of a palm to finger tip. A ban on the use of SCUBA was the main gear restriction measure and this was reported in Kenya, Madagascar, Mozambique and Tanzania. Only two countries, Madagascar and the Seychelles had developed management plans specific for sea cucumbers (Payet 2005). In the Seychelles, total allowable catch (TAC) limits for the key commercial species and limits on the number of licenses were regulated.

Table 18. Legislation, policies and management strategies in western Indian Ocean countries.

Country	Principle Legislation and implementing agency/ organisations	Related legislations	Policy/strategy	Regulations
Kenya	- Fisheries Act Cap 378 of 1989 (Revised 1991) - Fisheries Department - Fisheries Kenya Marine & Fisheries Research Institute	- Maritime Zone Act (Cap 371) of 1989 - Conservation and Management Act Cap 376 - Science and Technology Act Cap 250	- National Oceans & Fisheries policy 2008 - Fisheries management Bill 2009 (under debate) - Integrated Coastal Zone policy 2010	- licenses required for fishing and trading sea cucumbers - Beach Management Unit regulations empower communities to manage local fishing grounds - SCUBA ban
-Madagascar	- Ordinance 93 - 022 on 04/05/1993 - Ministry of Fisheries and Halieutics Resources - Fisheries Monitoring Centre	- Decree 94 - 112 on 13/02/1994 for general activities of maritime fisheries - Decree MECIE	- Fisheries management plan 2007-2011 - Integrated Coastal Zone	- Fishing license required for industrial and artisanal vessels - Fishermen identity required for small scale fishing (under process) - SCUBA ban - Regulation on minimum size of capture (11cm), processed trepang (8cm)
Mozambique	- Fisheries Law (Cabinet decree No 3/90, 1990) - Marine Fisheries Regulation 2003 - Ministry of Fisheries	- National Environmental Management Program (1995) - Act of Sea (No. 4/96)	- Fisheries Policy and Implementation strategy (1996) - Regulation of sea fishing (Ordinance 16/96, 1996)	- General Regulation of Fishing stipulates: Size limits (min length 20cm; min weight 250gr) - License required for harvesting sea cucumbers
Seychelles	Fisheries Act (1986)	- Maritime Zone Act (1999) - Environment Protection Act (1994) - National Parks and Nature Reserves Act (1969)	Management plan	Licenses required for fishing, processing and trading sea cucumbers TAC for
Tanzania mainland and Zanzibar	- Fisheries Act 2003 (mainland Tanzania) - Deep Sea Fishing Authority Act 1998	Coastal Management strategy 2003 - Environmental Management for Sustainable Development Act (1996) Zanzibar	- National Fisheries Policy 1997 (reviewed 2010) - Zanzibar Fisheries Policy 2002	- Licenses required for fishing of sea cucumbers - Licenses required for trading beche-de-mer - Licenses required for processing beche-de-mer - Minimum size limit for fresh sea cucumbers (10cm)

Source: Guide du responsable de la pêche et de l'aquaculture, MAEP 1987; Beadle 2005; Robinson *et al.* 2006; Conand & Muthiga 2007; Muthiga *et al.* 2007; Ochiewo *et al.* 2010.

Table 19 Sea cucumber fisheries management interventions and their level of implementation in Kenya, Madagascar, Mozambique, Reunion, the Seychelles and Tanzania. The information was based on an overview of the literature and expert assessment of the implementation of interventions during the regional workshop (Muthiga *et al.* 2010).

Management activities	Kenya	Reunion	Tanzania	Seychelles	Madagascar	Mozambique	Zanzibar
Legislation							
Sea cucumber fisheries	present (artisanal)	partly present	partly present	partly present	present	present	present
Policy	partly present	partly present	partly present	present	present	partly present	partly present
Management plans	absent	partly present	absent	proposed	present	absent	absent
Monitoring frameworks	partly present (catch data)	present	partly present	partly present	present but unreliable	partly present	partly present
Socioeconomic data collection	partly present	absent	partly present	partly present	present	No information	partly present
Regulations & other interventions							
Seasonal closures	absent	absent	absent	absent	partly present	absent	absent
Area closures (for fisheries & marine organisms)	present	present	present	present	present	present	present
Size limits	absent	absent	present not enforced	absent	absent	present	present, not enforced
Restocking program	absent	absent	absent	No information	absent	absent	absent
Stock assessment	absent	partly present	absent	present	present	present	absent
Gear restrictions (SCUBA)	present	present	present	absent	present	present	absent
Licenses (Fishing & Trading)	present	present	present	present	present	present	present
Education & extension	absent	absent	absent	No information	present	absent	absent
Research	partly present	present	partly present	partly present	present	partly present	absent
Mariculture & other interventions							
Willingness to adopt	absent	absent	absent	absent	present	absent	absent
Marketing	absent	absent	absent	present	absent	absent	absent
Organization of fishers (collectors, traders)	absent	absent	partly present	absent	absent	absent	absent
Processing (level and quality)	absent	absent	absent	present	absent	absent	absent
Quality assurance	absent	absent	absent	absent	absent	absent	absent

The analysis showed that except for closures, most of the management interventions were poorly executed and enforced in most of the countries with the exception of the Seychelles where management of the fishery was generally reported to be more effective. Additionally, management interventions such as restocking, education and extension and research were poorly developed in most countries. In Toliara, Madagascar, a mariculture project that combines both a community component and restocking component was initiated in 2000 (Jangoux *et al.* 2001). Although fisheries catch monitoring programs were present in nearly all the countries, these were often unreliable, in particular the collection and storage of catch and export data and the use of data for management were poorly executed. The analysis also showed that most of the national management agencies mandated to manage the sea cucumber fishery lacked the capacity to carry out basic management interventions including surveillance, enforcement and monitoring of the fishery which contributed to further overexploitation of the stocks.

DISCUSSION

Sea cucumbers are important for their ecological role (Hammond 1982; Uthicke 2001a; 2001b; Mangion *et al.* 2004), their economic value in fisheries (Toral-Granda *et al.* 2008; Purcell *et al.* 2012a; *et al.* 2013) and their potential for aquaculture (Lovatelli *et al.* 2004; Eriksson *et al.* 2012a; Purcell *et al.* 2012b). In the western Indian Ocean (WIO) sea cucumbers have been harvested for centuries and support coastal livelihoods primarily of artisanal fishers. Increased global demand for the processed product (beche-de-mer and trepang) led to overfishing and the reduction in sea cucumber stocks in most nations of the WIO (Conand & Muthiga 2007; Conand 2008). The primary responses to overfishing have been bans on harvesting and gear restrictions, yet knowledge to underpin these fisheries interventions were often lacking. It is impossible to adequately manage the fishery without an understanding of the biology, ecology and socioeconomics of sea cucumber fisheries. This report summarizes the findings from a regional project funded by the Western Indian Ocean Marine Science Association that was undertaken between 2007 and 2010 to address these knowledge gaps.

Ecological studies

Species inventories

A combination of literature review and taxonomic surveys revealed that the WIO has a rich and diverse fauna of sea cucumbers. Although no new species were recorded in the present study several samples were collected during the surveys that require taxonomic investigation. These include specimens tentatively identified as *Holothuria coluber* from Kenya, *Actinopyga obesa* from Reunion, and *Holothuria (Microthele) sp. pentard* from the Seychelles, and *Holothuria* and *Stichopus* a few specimen from Madagascar.

Patterns of biodiversity indicated relatively similar species and diversity in the Comoros (40 species), Kenya (44 species), Reunion (37 species), the Seychelles (35 species) and Tanzania (26 species). Madagascar that was intensively studied by Cherbonnier (1988) from records that spanned over a century was the most speciose with more than three times the number of species of the other countries. *Bohadschia atra* described by Massin *et al.* (1999) in Madagascar was reported in all the studied countries. In Kenya, where several surveys have been conducted (Humphreys 1981; Muthiga & Ndirangu 2000; Samyn 2000; Samyn & Vanden Berghe 2000; Samyn *et al.* 2001; Samyn 2003), cumulative searches in shallow waters showed an asymptote indicating that the Kenyan shallow water fauna is probably adequately sampled and future taxonomic efforts should focus on different habitats, deeper areas and more cryptic species. Comoros and Mayotte (Pouget 2003; 2004; Conand *et al.* 2005; Pouget 2005; Samyn *et al.* 2005; Eriksson *et al.* 2012b), and Reunion and Mauritius (Conand *et al.* 2010; Lampe 2013) were more recently studied but probably also

require more work in the deeper and more cryptic habitats. The sea cucumber fauna is least understood in Tanzania where studies focused on Pemba (Samyn 2003) and Zanzibar (Eriksson *et al.* 2010) Islands, and Mozambique where very little taxonomic work has been done on sea cucumbers.

In the first zoogeographic study of the WIO using data from Kenya and Tanzania, Samyn & Tallon (2005) noted that new species continued to be discovered as more surveys were conducted in the region. Moreover, Samyn *et al.* (2005) predicted from a gap analysis comparing the Comorian fauna with north Mozambique and the west coast of Madagascar, that the fauna of the Comoros could be as high as 50 species. This indicates that the current diversity data are probably an underestimation. The biodiversity of the sea cucumbers of the region will therefore continue to generate interest not only because new species are likely to continue to be discovered but also because of the numerous taxonomic uncertainties in the fauna. For example, a high percentage of the descriptions of Cherbonnier's (1988) were based on single specimen or small individuals that could be juveniles of already described species (Samyn & Tallon 2005). In addition, species are being redescribed such as *H. scabra versicolor* that is now called *H. lessoni* (Massin *et al.* 2009). It is also expected that specimen collected during this project will generate more taxonomic enquiries including of *H. impatiens* a species complex, *H. verrucosa* and *H. fuscocinerea*, and *Polyplectana spp* in Reunion (Conand *et al.* 2010), *H. coluber* (Muthiga pers. comm.), and *H. flavomaculata*, and *H. arenacava* and relatedness to *H. isuga* from the Indo Pacific (Samyn pers. comm.).

Distribution and abundances

Sea cucumbers were ubiquitous and common throughout the studied sites but the distribution and abundance were highly variable ranging from less than 1 to 2500 indiv.ha⁻¹ depending on the species and the site. This heterogeneity is not unusual for benthic marine invertebrates (Conand 1989a; Eriksson *et al.* 2012b). The overall average abundance was less than 10 individuals.ha⁻¹ in Kenya and Zanzibar, three times as abundant in Madagascar and almost three orders of magnitude higher in Reunion. Reunion is a volcanic island with a few small reefs mainly on the western to the south side of the island. There is no history of fishing of sea cucumbers on the island (Conand 2008) and so the high densities could partly be due to protection. The highest densities were of the low value species *H. atra* and *H. leucospilota* hence habitat factors may also play a role in their densities. Comparison with estimates from previous studies in the studied countries indicated similar results in Kenya, Seychelles, Madagascar and Zanzibar (Muthiga & Ndirangu 2000; Aumeeruddy *et al.* 2005; Conand & Muthiga 2007; Eriksson 2010). Results from other parts of the Indo-Pacific indicated average densities that were similar to Reunion for example in Indonesia and Malaysia densities averaged 500 to 600 ind.ha⁻¹ (Choo 2008 in Toral-Granda *et al.* 2008).

The most common species were *H. atra* and *H. leucospilota* that occurred in the highest densities in Kenya, Reunion and Zanzibar. These species are also common throughout the Indo-Pacific (Conand 1989a; 2004b; Toral-Granda *et al.* 2008). *Stichopus* was very abundant in Reunion while *H. notabilis* and *S. horrens* were only abundant in Madagascar and had not been previously studied before this project. In general, species of medium to high commercial value occurred in very low densities in Kenya, Madagascar and Zanzibar. Although comparative historical data from previous studies at the same sites are scarce, the few surveys that are available indicate a trend of decreasing abundances for species of commercial value. For example, in Kenya, *H. scabra* was reported at densities of 0.1 - 1 ind.ha⁻¹ in 1999 (Muthiga & Ndirangu 2000) while in the recent surveys no individuals of this species were recorded in 93 belt transects in the same locations (Odhiambo 2007). Comparisons of densities in the Comoros also showed decreases in the species of commercial value (Samyn *et al.* 2005), while in Madagascar, the biomass of *H. notabilis* which was not harvested prior to 1996, decreased drastically by three orders of magnitude from 60,000 ind.ha⁻¹ (Mara *et al.* 1997) to 200 ind.

ha⁻¹ (Razafimandimby 2008). A reduction in the abundances of commercial species has been reported in many tropical countries where sea cucumbers are harvested (Toral-Granda *et al.* 2008; Purcell *et al.* 2013).

Because density and distribution are affected by several factors including the survey method, the scale, habitat and management interventions such as closures and gear restrictions and because some of these factors act synergistically, it is often difficult to elucidate the specific factors affecting distribution and abundance of sea cucumbers. In this study, the main survey method used was the belt transect method, however, the transect size differed which may introduce inconsistencies due to scale across the survey sites. Nonetheless, comparisons between sites showed the importance of habitat in controlling distribution and abundance of sea cucumbers. A significant relationship was found between habitat and abundance of sea cucumbers but this was not consistent across habitats. For example, there were significantly more species and individuals in reef lagoons than in reef flats in Kenya (Muthiga & Ndirangu 2000; Orwa *et al.* 2009). In Reunion, there were higher densities in inner reef flats than in back reef habitats (Conand & Mangion 2002; Conand 2005; Fabianeck & Turpin 2005; Burgos & Hollinger 2007). Studies in Kenya also showed the lowest densities of sea cucumbers in seagrass beds compared to reef habitats (Muthiga & Ndirangu 2000), with the exception of *Synaptamaculata* that occurred in relatively high densities in seagrass beds (Orwa *et al.* 2009). On the other hand other studies have shown densities of sea cucumbers were significantly higher in seagrass habitats than in inner reef slopes, microatolls, outer reef flats and detrital ridges in Madagascar (Mara *et al.* 1997; Conand 1999).

Other factors that impacted sea cucumber populations included depth, water flow and substrate. In the Seychelles, there were significantly higher densities of sea cucumbers in shallow than intermediate or deep strata in the Amirantes and Mahé Plateaus (Aumeeruddy *et al.* 2005). This is consistent with other studies that showed densities varying with depth (Zhou & Shirley 1996; Eriksson *et al.* 2012b). The substrate nutrient content and water flow were also shown to play a role in sea cucumber densities in Reunion where higher densities occurred at more eutrophic sites (Taddei 2006). Substrate type has also been found to be important in studies in the Indo-Pacific (Shiell & Knott 2010) and Mayotte (Eriksson *et al.* 2012b).

Another key element in the regulation of sea cucumber populations is recruitment of new individuals into the population. However, juvenile sea cucumbers are rarely observed in nature, making it difficult to study the factors that control recruitment (Shiell 2004a; 2004b). In this project, juvenile individuals of *A. echinites* were observed in December during the peak reproductive period for this species (Kohler *et al.* 2009). Juvenile *H. atra* were also observed in Kenya between August and December during the north-east monsoon season. Although the recruitment data that was collected during this project is only observational information, this is the first such data for the region and are useful for designing more comprehensive studies on the factors that may affect recruitment and the effects of recruitment on the population.

The density and diversity of sea cucumbers were also shown to be affected by closures. Higher densities of sea cucumbers were recorded in marine protected areas (MPAs) in Kenya than in fished areas (Odhiambo 2007; Orwa *et al.* 2009). This was consistent with the findings from a previous study in Kenya (Muthiga & Ndirangu 2000). Eriksson *et al.* (2010) also reported higher densities and diversity of sea cucumbers at the Chumbe Is Coral Park in Zanzibar as did Cariglia (2013) in the Seychelles than at the adjacent fished reefs. Higher densities of sea cucumbers were also reported in studies in Mayotte (Eriksson *et al.* 2012b) and Reunion (Fabianeck & Turpin 2005; Burgos & Hollinger 2007) where sea cucumbers are not fished indicating the potential effects of protection from fishing. However, although the density of sea cucumbers may increase under protection in a particular MPA, the broader effects on the stocks and fishery are unknown. This is because although MPAs are suggested as an effective fisheries management tool, their use in the management of sea cucumbers has received little attention resulting in limited information on the efficacy of

MPAs. In addition, because sea cucumbers are broadcast spawners, a minimum distance is required between individuals to ensure fertilization and reproductive success (Bell *et al.* 2008a). Overfishing may reduce the population density of sea cucumbers below a threshold that maintains reproductive success making it extremely difficult for populations to recover (Uthicke *et al.* 2004; Hearn *et al.* 2005; Bell *et al.* 2008a). This project provided some preliminary information on the effects of MPAs in the WIO but more studies are needed to test the efficacy of MPAs and other tools such as mariculture for restoration of sea cucumber stocks (Bell *et al.* 2008a; 2008b).

Biological studies

Morphometric and life history strategies

One of the most important features of the life history strategy of organisms is the appropriate allocation of resources towards growth, maintenance and reproduction so that fitness is maximized (Gadgil & Bossert 1970). Body size is the main life history trait against which other morphological and physiological features are measured. Because sea cucumbers have soft body walls that can expand and shrink, three different measures of body size, total wet weight, gutted wet weight and length were used in this project. Body size of the different species varied but the allometric relationships between the different measurements of body size correlated within each species. In particular, all the species showed significant correlations between total wet weight and gutted wet weight, and gutted weight and body length suggesting that these measurements were a reliable indicator of body size in the respective species. Because the sample sizes for the studied species were large, these equations will be useful for estimations of body size in future population and growth studies.

Body size has also been related to reproductive fitness because it is assumed that the larger body size results in greater reproductive success (Williams 1975). When food availability is not limited, organisms will allocate a higher proportion of resources to reproduction and larger individuals will therefore have a higher reproductive fitness (Thompson 1982). This is mainly based on the observation that larger individuals have larger gonads that produce more gametes. In sea cucumbers where gonads have little connective tissue, the weight of a ripe gonad is largely attributed to gametes and hence gonad size is a reliable indicator of reproductive effort. This was consistent with findings in this project where gonad weight and tubule length (another measure of gonad size) were both significantly correlated with reproductive effort or fecundity (measured as the number of oocytes in the gonads) in *H. fuscogilva* and *H. scabra* (Muthiga & Kawaka 2009; Muthiga *et al.* 2009). Larger females have been shown to produce more eggs in several other species of sea cucumbers (Conand 1993; Toral-Granda & Martinez 2007) and sea urchins (Muthiga 1996).

The sex ratio and the differences in the sizes of the sexes are also life history traits of relevance to populations. Because the production of female gametes has a higher energetic cost than male gametes, differences between the body sizes of the sexes and the sex ratio also have implications in the way populations allocate resources to reproduction. The species in this study displayed different life history strategies. While *A. echinites* and *H. leucospilota* had larger females than males with significantly larger gonads than males, the sex ratios of these species were also significantly skewed towards females (Gaudron *et al.* 2008; Kohler *et al.* 2009). In *H. fuscogilva*, on the other hand, although females were not larger on average than males, they had significantly larger gonads while the sex ratio was skewed towards males (Muthiga *et al.* 2009). In *H. scabra*, there were no differences between the body sizes of the sexes or between the gonad sizes of the sexes and the sex ratio was also skewed towards males (Muthiga & Kawaka 2009; Kithakeni pers comm.).

By producing more and larger females with larger gonads, the populations of *A. echinites* and *H. leucospilota* in Reunion adopted the life history strategy with the highest potential reproductive success (Levitan 1991). A previous study in Kenya also reported a similar life history strategy in *H. arenacava* (Muthiga 2006) and the sea urchin *Echinometra mathaei* (Muthiga & Jaccarini 2005). However, reproductive success is also dependent on the density and distribution of sexually mature adults (Levitan 1991; 2005). *Holothuria leucospilota* had one of the highest population densities recorded in the WIO suggesting that food availability was probably not a limiting factor for this species, allowing it to use a highly successful reproductive strategy to become one of the dominant sea cucumbers in Reunion. On the other hand, the sex ratio in the high commercial value *H. fuscogilva* and *H. scabra* suggested an impact from fishing. Comparison with a previous study showed that sex ratios had shifted from unity in 1998 – 2001 (Muthiga & Ndirangu 2000) to the production of fewer females in 2006 – 2007 (Muthiga & Kawaka 2009; Muthiga *et al.* 2009). The shift to more males and the reduction in population density could significantly affect the overall reproductive success and hence the stocks of these species in Kenya. Shifts in sex ratio towards more males due to fishing pressure have also been reported for *H. scabra* in the Red Sea (Hasan 2005) and *H. whitmaei* in Australia (Shiell & Uthicke 2006).

The size at sexual maturity is not only important for fisheries management by helping to set minimum harvest sizes, this life history trait can also be affected by fishing pressure. A decrease in the size at sexual maturity can be beneficial by helping a species adapt to fishing pressure; for example early sexual maturity increases the possibility of producing young before capture (Ricker 1981). However, a decrease in size at sexual maturity could also be detrimental if the change is not balanced by a commensurate increase in fecundity since reproductive output is lower in smaller individuals. In this study, the size at sexual maturity was estimated for *A. echinites*, *H. fuscogilva*, *H. leucospilota*, *H. scabra*, *H. notabilis*, *S. horrens*, the first such data for these species in the WIO (Gaudron *et al.* 2008; Razafimandimby 2008; Kohler *et al.* 2009; Muthiga & Kawaka 2009; Muthiga *et al.* 2009). Conand (1981;1993) also estimated sizes at sexual maturity for several sea cucumber species including *H. fuscogilva* and *H. scabra* in New Caledonia. Because the methods used to calculate the size at sexual maturity for these species differed, it is difficult to make reliable comparisons between these data and Conand (1993). However the average sizes of these species in the catch in Kenya showed a decrease when data from the period 1998 – 2001 (Muthiga & Ndirangu 2000) was compared with data for the 2006 – 2007 period (Muthiga & Kawaka 2009; Muthiga *et al.* 2009) suggesting a potential change in the size at sexual maturity, additional evidence for a detrimental impact of fishing on these species.

Reproductive cycles

Sea cucumbers exhibit variable patterns of reproduction and gametogenesis and spawning are controlled by different factors (Conand 1989a; Smiley *et al.* 1991; Sewell *et al.* 1997). For example, water temperature and photoperiod have been reported to control gametogenesis (Conand 1989a; 1993; Morgan 2000; Ramofafia *et al.* 2003; Drumm & Loneragan 2005), while spawning has been reported to be triggered by changes in salinity (Krishnaswamy & Krishnan 1967), temperature, light intensity and food availability (Conand 1981; Cameron & Fankboner 1986), water turbulence (Engstrom 1980), phytoplankton blooms (Himmelman 1980) and moonlight (Babcock *et al.* 1992; Mercier *et al.* 2007). Although earlier studies suggested that tropical species should exhibit continuous reproduction due to the reduced environmental variability in the tropics (Smiley *et al.* 1991), more recent studies have shown both annual (Reichenbach 1999; Drumm & Loneragan 2005, Muthiga 2006; Rasolofonirina *et al.* 2005), biannual (Kithakeni & Ndaro 2002) and continuous reproductive patterns (Guzman *et al.* 2003) at tropical locations.

The reproductive cycle of sea cucumbers is often tracked using the gonad index method (Gonor 1972), however, this method only yields meaningful results when there is no significant relationship between body size and the gonad index (Grant & Tyler 1983). In all but one of the species studied, there was no significant relationship between the

gonad index and the gutted weight, which indicated that changes in gonad index over time were a reliable indicator of the reproductive stages for these species. The exception was *H. scabra* in Tanzania where a weak but negative relationship was found between total body weight and gonad index indicating that using total weight to calculate gonad index was not as reliable a measure of reproductive changes. This is not surprising since total weight can vary considerably depending on the amount of coelomic fluid and gut material in sea cucumbers (Conand 1989a; 1993).

The main mode of reproduction for all the studied species was sexual and highly synchronized between the sexes. This has been shown in other echinoderms in the region (Muthiga 2003; 2006; Muthiga & Jaccarini 2005). Reproduction through fission has previously been reported in *H. atra* and *S. chloronotus* in Reunion (Conand 1996; Conand *et al.* 2002; Conand 2004b). The pattern of reproduction varied amongst the species, closer to the equator (4 - 7°S), *H. scabra* displayed a biannual pattern with two spawning periods (Muthiga *et al.* 2009) while *H. fuscogilva* displayed an annual pattern with a single extended spawning period (Muthiga & Kawaka 2009). Further away from the equator (21 - 23°S), *S. horrens* and *H. notabilis* (Razafimandimby 2008) displayed an annual pattern with a single extended spawning period, while *A. echinites* (Kohler *et al.* 2009) and *H. leucospilota* (Gaudron *et al.* 2008) had an annual pattern with two short spawning periods which was similar to *H. leucospilota* and *H. atra* on the Great Barrier Reef Australia (Franklin 1980; Harriot 1982). The pattern of reproduction was not species specific, for example, while this and a previous study showed that *H. scabra* had a biannual pattern closer to the equator (Kithakeni & Ndaro 2002; Muthiga *et al.* 2009), the species displayed an annual pattern at higher latitudes in Madagascar (Rasolofonirina *et al.* 2005). On the other hand, *H. fuscogilva* had an annual pattern across its latitudinal range in east Africa (Muthiga & Kawaka 2009), the Maldives (Reichenbach 1999), the Solomon Is (Ramofafia *et al.* 2000) and New Caledonia (Conand 1993) suggesting that this is the common strategy for this species.

Three of the studied species showed significant and positive correlations between gonad index and sea surface temperature (Gaudron *et al.* 2008; Muthiga & Kawaka 2009; Muthiga *et al.* 2009; Kithakeni pers. comm) suggesting that SST played a role in gametogenesis and spawning in these species. However, these findings are compounded by the fact that four of the studied species also showed significant correlations between gonad index and light (Gaudron *et al.* 2008; Razafimandimby 2008; Kohler *et al.* 2009; Muthiga *et al.* 2009). This is not surprising since the warmest times of the year in the WIO generally coincide with the highest light intensity and productivity. This makes it difficult to elucidate whether these factors act separately or synergistically to entrain gametogenesis and spawning without experimentation. Lunar periodicity that has been shown to influence reproduction in some sea cucumber species (Babcock *et al.* 1992; Mercier 2007) did not show a relationship with the gonad index in any of the species studied except in *H. fuscogilva* which showed a weak but significant relationship between lunar periodicity and gonad index. This suggests that spawning in *H. fuscogilva* could be cued by changes in moonlight but the exact mechanism would have to be investigated. Although the relationship between rainfall and gonad index was evaluated for all six species studied, no relationship was found suggesting that rainfall is probably not an important factor in the reproduction of these species of sea cucumbers. Guzman *et al.* (2003) also failed to find a relationship between rainfall and the gonad indices of *Isostichopus badionotus* and *H. mexicana* in Panama.

The reproduction studies provided key information on reproductive parameters for fisheries management such as information on size at sex maturity that is used to set size limits, and on reproductive seasons that is used to set seasonal closures.

This information was compiled for the studied species and countries (Table 20) and formed the key recommendations that were discussed during the regional workshop (Muthiga *et al.* 2010).

Table 20. Recommended management interventions based on the reproductive season and size at sexual maturity (gutted weight, g; length, cm) of fished species in the western Indian Ocean.

Species	Country	Management interventions
<i>H. scabra</i>	Kenya	Closures Nov - Dec, minimum sizes of 22.6 g or 16 cm
<i>H. scabra</i>	Tanzania	Closures Dec - Jan, minimum size 16.8 cm
<i>H. scabra</i>	Madagascar	Closures Nov - May
<i>H. fuscogilva</i>	Kenya	Closures Dec - Mar, minimum size 1167 g or 32 cm
<i>H. leucospilota</i>	Kenya	Closures Jan - April, minimum size 39 g
<i>H. leucospilota</i>	Reunion	No fishery- Closures Feb, minimum size 55 g
<i>A. echinites</i>	Reunion	No fishery- Closures Dec-Jan, minimum size 45 g
<i>H. atra</i>	Reunion	No fishery- Closures Dec-Feb
<i>S. chloronotus</i>	Reunion	No fishery- Closures Jan-Feb, Nov, minimum size 50 g
<i>H. notabilis</i>	Madagascar	Closures Aug - Dec, minimum size 20 g or 9.5 cm
<i>S. horrens</i>	Madagascar	Closures Nov - Mar, minimum size 170 g, 25 cm

Source modified from Muthiga *et al.* 2010

Over-fishing has reduced population densities in some countries however to the extent that individuals may be too far apart to successfully reproduce, consideration of restocking programs was therefore recommended for these countries. Mariculture has developed to the commercial scale in Madagascar (Jangoux *et al.* 2001; Rasolofonirina *et al.* 2004; McVean *et al.* 2005; Lavitra *et al.* 2009; Robinson & Pascal 2009; Lavitra *et al.* 2010) and several other countries in the WIO have shown an interest. In addition, a wealth of information is now available on sea cucumber culture such as studies on the biology of commercial species (Hamel *et al.* 2001), guidelines for restocking and stock enhancement (Bell & Nash 2004; Purcell 2004; Bell *et al.* 2008a; 2008b), several publications on various aspects in the culture of *H. scabra* (Purcell *et al.* 2006b; Agudo 2007) and a global review of sea cucumber aquaculture (Lovatelli *et al.* 2004). The experiences gained from these studies and mariculture projects can provide the information needed to advance the development of mariculture and restocking programs in the WIO.

Socioeconomics and fisheries management

Socioeconomic characteristics of sea cucumber fisher communities

The studied countries differed markedly in the general characteristics of the fishery and the socioeconomic conditions of the fishers. In Reunion which has a high Human Development Index (HDI²) of 0.97, the reefs are managed as a permanent no-take area and no harvesting of sea cucumbers occurs. The Seychelles on the other hand with a HDI of 0.84, had a relatively well-managed sea cucumber fishery. Kenya, Madagascar, Mozambique and Tanzania are low HDI (0.47, 0.44, 0.32 and 0.40 respectively) nations and the sea cucumber fisheries were predominantly artisanal and poorly managed.

Although the socioeconomic conditions of the fishers differed they generally corresponded with the level of development in each country. The level of education was higher and the household size smaller in the Seychelles compared to Kenya, Madagascar and Mozambique (Pinault & Conand 2007; Macamo 2009; Ochiewo *et al.* 2010). Men dominated the fishery in Kenya and the Seychelles, as in most countries where skin or SCUBA diving was used to

²hdr.undp.org

collect sea cucumbers. Women and children composed ten to twenty-five percent of the harvesters in Madagascar, Mozambique and Tanzania. The types of gear utilized in the fishery also depended on the economic development of the country, while small semi-commercial vessels were used in the Seychelles, dug-out canoes, sailboats, motorboats and outriggers were more common in the other countries. Much of the catch was collected through gleaning in shallow intertidal areas and skin diving in deeper subtidal areas common in most of the countries and SCUBA in deeper waters. The fisheries in the different countries were therefore strongly influenced by the ease of access to fishing grounds and the use of low cost gears. These findings are consistent with sea cucumber fisheries in most parts of the world (Toral-Granda *et al.* 2008; Anderson *et al.* 2011a; 2011b; Purcell *et al.* 2013)

A detailed analysis of the contribution of the sea cucumber fishery to livelihoods was outside the scope of the study, however, estimates of catch per unit effort, earnings from sea cucumbers and the level of dependence on the fishery provided an indication of the importance of the fishery for livelihoods. For example, of the villages studied, up to two-thirds of fishers focused on sea cucumber harvesting in Kenya, Zanzibar and Madagascar (Ochiewo *et al.* 2010; Andriatsimalona 2007; Rakotomahéfa 2007; Raymond 2008; Razafimandimby 2008). The earnings from the fishery however, differed depending on the mode of fishing and the value of the catch. For example in Kenya, earnings from low-grade sea cucumbers were equivalent to the minimum wage range for casual labour, while earnings from high grade catches were more than ten times the daily wage (Ochiewo *et al.* 2010). In addition, in Zanzibar, harvesters that used SCUBA who comprised only a small percentage of the fishers, earned almost twice as much as fishers using gleaning and skin diving; a reflection of the fact that SCUBA divers not only had a higher CPUE, but also collected more of the higher value species than the other two groups (Raymond 2008). Village processors earned about seventy-five percent of daily earnings from the fishery (Raymond 2008; Ochiewo *et al.* 2010). Higher earnings by processors and SCUBA collectors was also reported in Madagascar in a more recent economic evaluation of the fishery (Andrianaivojaona 2012).

In most of the studied countries, the average daily earnings from the fishery was less than 1USD per day, however, very few fishers limited their fishing activities to sea cucumbers. Depending on the country, fish, octopi, bivalves, sea urchins and crustaceans were also collected. In addition, fishers supplemented their incomes with a range of other income generating activities including casual employment, small-scale trade and subsistence farming (Andriatsimalona 2007; Rakotomahéfa 2007; Raymond 2008; Razafimandimby 2008; Ochiewo *et al.* 2010). This is a common risk spreading strategy that occurs amongst poor communities that are resource-dependent in tropical fisheries (Andersson & Ngazi 1998). The general flow of profits increased as the product moved up the value chain, for example, Ochiewo *et al.* (2010) estimated a 330% increase in profits from fresh to processed products for the high value species *H. scabra* in Kenya. Although processors and some traders were often members of the local community and therefore contributed to the local economy, most traders, some processors and all exporters were based in the larger towns and therefore, there was a net flow of economic value away from the villages. This is consistent with sea cucumber fisheries in most part of the world where the bulk of the profit is exported away from the fishing grounds (Toral-Granda *et al.* 2008; Purcell *et al.* 2013).

Our results showed that the studied communities except for the Seychelles and Reunion were poor and highly dependent on marine resources. A combination of factors limited their ability to optimize earnings from the sea cucumber fishery including limited processing skills, limited access to financial capital and lack of price negotiating power (Raymond 2008; Ochiewo *et al.* 2010). Interviews of sea cucumber fishers in Kenya, Madagascar and Zanzibar showed that there was great interest in programs to provide capital to improve vessels and gear, and training in harvesting, processing and mariculture (Beadle 2005; Nilsson 2008; Raymond 2008). However, this situation is complicated by the fact that most sea cucumber fisheries in the region are overfished (Conand & Muthiga 2007; Conand 2008; Eriksson *et al.* 2010),

therefore fisheries management interventions that focus on intensifying fishing and not restoring stocks would likely fail, further threatening the economic contribution of this fishery to community livelihoods.



Figure 14. A) Families constructing their sea cucumber farming pens in Nosy Be. (J. Razafiarison). B) Young girls removing drift seaweed from their sea cucumber pen in Tampolove (G. Robinson). C) Juvenile sandfish transported by fishing boat, from the nursery in Belaza to grow-out sites in Velondriake 250km north (G. Cripps). D) The first harvest of sea cucumbers from a 10m x 10m demonstration pen in Ambolimoke after 11 months grow-out. (G. Robinson).

The only poverty alleviation intervention targeted specifically at the sea cucumber fishery that was reported in the region was sea cucumber mariculture (Fig. 14). The oldest mariculture project in the region started as a research project based in Toliara Madagascar that evolved from the development of hatchery systems for *H. scabra* (Conand *et al.* 1998b; Jangoux *et al.* 2001; Rasolofonirina *et al.* 2004), to the involvement of village communities in micro-farms (Tsiresy *et al.* 2011), to the establishment of a trade company Madagascar Holothurie in 2008 (Eeckhaut *et al.* 2008). In 2012, Madagascar Holothurie became a shareholder in a much larger company Indian Ocean Trepang whose goal is to produce ~2 million *H. scabra* yearly by 2015. Despite several challenges including diseases of some animals in the research project and the theft of more than 3000 juveniles in a community farm (Robinson & Pascal 2009), the project provides useful lessons for the efficacy of community-based mariculture of sea cucumbers (Fig. 14) including experiences in technological specifications, marketing options and governance challenges in the region. Experimental trials for sea cucumber mariculture research were also initiated in Tanzania (S. Stead pers. comm.) and in Kenya the Fisheries Department has also shown an interest in sea cucumber mariculture as part of the larger national program of aquaculture development (Mueni pers. comm.).

Production trends

A total of 32 species of sea cucumbers are harvested throughout the WIO (Conand & Muthiga 2007) with Madagascar having the highest number of species harvested (30 species). Eight main species are harvested in all the countries surveyed including the high value species *H. fuscogilva*, *H. scabra*, *H. nobilis*, *Thelonata ananas* and the medium value *Actinopyga miliaris*. These are the same species reported in previous studies (Conand & Muthiga 2007) and no new species were introduced into the fisheries. *Holothuria nobilis* and *S. horrens* that were not harvested prior to 1997 in Madagascar continue to contribute a high percentage of the harvest from villages in southwest Madagascar, but they are medium to low value species (Rasolofonirina 2007; Razafimandimby 2008).

The countries had varying levels of production and in most cases, fisheries data were not reported for individual species, were not easily accessible, and showed inconsistencies between records of national fisheries departments, export data and data reported to FAO, making it difficult to estimate effort (Marshall *et al.* 2001; Beadle 2005; Conand & Muthiga 2007). Nonetheless, despite the poor quality and inconsistencies in production data, general trends could be discerned. Previous reviews indicated that production of beche-de-mer in the studied countries had declined between 40 and 80% over the last decades (Conand 2004c; 2008) with the exception of Madagascar and the Seychelles where production has remained relatively stable in the last decade. These two countries together contributed between 40 and 60% of the production of FAO area 51 that encompasses most of the countries of the WIO including the Red Sea, from 2004 to 2010. Information from an assessment of the fishery in Mozambique (Macamo 2009) also showed weak management, and despite licensing requirements (annual fee of ~47 USD) and a size restriction (20cm and 250 gm), few fishers were aware of these rules, hence compliance was low and surveillance was weak. There were also reports of illegal fishing by foreign fishers, severe depletion of sea cucumbers at Quissanga and Mongicual within the fishing grounds surrounding Mozambique Is. and reductions in sizes of high value species.

Management of the sea cucumber fishery

Conand & Muthiga (2007) reviewed the management of the sea cucumber fishery in the five studied countries. Subsequent assessments during the project indicated that in all cases sea cucumbers were managed by fisheries departments, except in marine parks and reserves where they were under the jurisdiction of conservation agencies (Kenya and Madagascar), or tourism agencies (Mozambique and Tanzania). However, within these MPAs, there were no specific management interventions for sea cucumbers. The countries had various legislative and regulatory instruments that governed the fishery including: Fisheries Acts and related legislation; policies and regulations such as licensing of collectors, traders and exporters; statutes and ordinances regulating or restricting gears including banning of SCUBA, size restrictions, total allowable catch and seasonal closures. The copies of many of these documents were often difficult to access and on the ground implementation was weak in most countries (Marshall *et al.* 2001; Beadle 2005; Nilsson 2008; Eriksson *et al.* 2010; Ochiewo *et al.* 2010).

Different management responses were reported in the different countries, the most common regulation being the licensing of collection, trade and export of sea cucumbers that was reported in all the countries. Records on the number of licenses, and details of the licenses including who and where the fishing was licensed were not easily accessible, making it difficult to enforce this regulation. The most extreme management measure was an outright ban on the collection and trade of sea cucumbers that was instituted in Tanzania mainland in 2003 (Mgaya & Mmbaga 2007), in Mauritius in the islands of Rodrigues, Agalega and St Brandon in 2009 (S. Kundun, S. Jhumum and S. Meunier pers. comm.), and in Mayotte (France) and the Republic of the Comoros in 2004 (FAO 2013). Anecdotal reports indicate that the harvest of sea cucumbers continues in Tanzania with some of the catch being exported possibly out of Kenya or

Zanzibar where harvest of sea cucumbers is still allowed under the regional government regulations (Muthiga *et al.* 2007; Nilsson 2008; Eriksson *et al.* 2010; *et al.* 2012c). The effectiveness of these bans was difficult to evaluate since the processes that led to the bans were poorly documented and there was no subsequent evaluation of compliance. However, anecdotal evidence indicated that the ban was respected in Mayotte but not in the Comoros, where governance of fisheries is complicated by conflicts in jurisdiction between the government and Island authorities. In the Seychelles, SCUBA use is regulated by specific rules for example training and gear inspections (Aumeerudy & Conand 2008).

Other management interventions included minimum size limits for fresh and processed products that were implemented in Kenya, Madagascar Mozambique and Zanzibar (Muthiga *et al.* 2007; Rasolofonirina 2007; Nilsson 2008; Macamo 2009) and a ban on the use of SCUBA equipment for harvesting sea cucumbers that was implemented in Kenya. As with the moratorium on harvest, there was little evidence of the process that led to the implementation of these management actions and little evidence of post-ban monitoring. For example, in Kenya where the SCUBA ban was implemented in 2003 after an assessment revealed over exploitation of the fishery (Muthiga & Ndirangu 2000), a review of compliance three years after the ban indicated that the use of SCUBA continued (Beadle 2005). There was a general lack of awareness of the regulations by fishers and fisheries officers and there was no monitoring of compliance. In addition, SCUBA divers were reported to be operating on a roving basis, moving from one fishing site depleting stocks then moving to another site. Reports of this type of fishing where divers from outside the community/country invade an area have also been reported in the Chagos Archipelago (Spalding 2006), the Seychelles (Le Quotidien 2001; Aumeeruddy 2007) and Zanzibar (Eriksson 2012c). In Madagascar illegal fishers using SCUBA from land based or sea based camps (large boats) were reported to fish intensively at a site before moving to another site after a few days to several weeks (Rasolofonirina *et al.* 2004). It is difficult to encourage local communities to comply with regulations when migrant fishers appear to break these regulations with impunity.

Some countries also had regulations on the minimum harvest size. Minimum size limits are usually set based on the size at first sexual maturity and should be species based as well as calculated for specific locations (Bruckner 2006; Purcell 2010). It is not clear how the size limits in Mozambique, Madagascar and Zanzibar (20cm, 11cm and 10cm respectively) were decided. Given that the sea cucumber fisheries in the region are multispecies, the current size limits have a limited ability to have a positive impact since they are not specific for individual commercial species or locations. Interviews of fishers showed that in Kenya, a voluntary size limit of no less than the length from palm to fingertip is used. This indicates an understanding of the need to collect larger animals and willingness to self regulate (Beadle 2005). In addition to ensuring that the minimum size limits are selected on a scientific basis, making this information widely available and monitoring compliance will increase the effectiveness of this management measure.

Finally, catch limits are a common management intervention that has been shown to be effective in regulating fishing especially of key commercial species. Only the Seychelles had implemented catch limits based an assessment of stocks undertaken in 2003 - 2005 (Aumeeruddy *et al.* 2005) and calculation of total allowable catch for key commercial species. The objective of catch limits is to regulate fishing effort to levels that are sustainable, which requires scientific expertise and a fairly rigorous surveillance and reporting system. Catch limits would therefore be more challenging to implement in the other countries of the region where fishing is primarily artisanal. Although no specific evaluation has been conducted of the effectiveness of this management measure in the Seychelles, anecdotal information indicates that it is meeting management objectives although there are some challenges for example conflicts between fishing operators due to limits on the number of licenses (Aumeeruddy & Conand 2008), and difficulties in monitoring the catch at the level of fishers and reconciling this to the amount processed (Pinault & Conand 2007). Seychelles is also the only country with a management plan specific to the regulation of the sea cucumber fishery (Aumeeruddy 2007).

CONCLUSION AND RECOMMENDATIONS

The regional review conducted at the beginning of the project (Conand & Muthiga 2007) highlighted the decline and weak management of the sea cucumber fishery in the western Indian Ocean and further scientific findings from this MASMA project indicated persistent serious challenges for this fishery in the five studied countries. Several factors are driving the continued exploitation of this fishery despite the fact that its continued decline has negative implications for coastal economies and livelihoods. Securing the sustainability of this fishery is therefore an important development goal for the nations of the WIO. The following summarizes the key challenges facing this fishery and recommendations for addressing them broadly listed in order of priority.

(1) Management capacity

One of the main challenges was the weak capacity for management that was a problem not only in the studied countries but also across the WIO region. Some interventions had been implemented to improve management as detailed above however, many of these actions were not based on a thorough assessment of the fishery and were often ineffective partly due to lack of consistent monitoring, surveillance and enforcement. Without an improvement in the management capacity for this fishery, there is little chance of reversing the decline. The key recommendation is therefore the development of management plans for this fishery. The management planning process including reviewing the current system, the collection of baseline information, defining the objectives of the fishery, setting measurable targets, monitoring and enforcement, and defining mechanisms for stakeholder engagement are all important aspects that will build the overall capacity for management across the management institution. In addition, the process should be adaptive such that findings from performance evaluations can be used to make the needed adjustments or to introduce new management actions in an iterative process.

Partnerships with fishers, exporters and traders to encourage voluntary reporting and enforcement, and with customs officials, scientists and conservation area officials could reduce the burden of research and surveillance and increase the eyes on the ground. Such partnerships although useful in improving overall management should not replace consistent and regular follow-up action by the management authority. Training and stakeholder engagement was also highlighted at an FAO workshop that was conducted in Zanzibar in 2013 on ecosystem approaches to management of sea cucumbers (SCEAM Indian Ocean; FAO 2013). Fisheries officers from fourteen countries of the Indian Ocean including most of the countries of the WIO attended the workshop. Specific skills that were recommended included skills to assist in surveillance and monitoring such as species (live) and product identification targetted at different management agencies including fisheries officers, conservation managers and customs officials (FAO 2013). A species identification guide of commercial sea cucumber species that was developed by FAO (Purcell *et al.* 2012a) should serve as a useful learning tool.

(2) Knowledge gaps

The second crucial challenge is a large gap in the knowledge needed for the management of this fishery. For example, data on the stocks of sea cucumbers especially the biomass and stock delineation of commercial species was scarce. Although this project collected or reconstructed (from the literature) abundance data of sea cucumbers in some of the countries, this was not sufficient and stock data were lacking in most countries in the region. Given that several species of sea cucumbers that occur in the region have recently been listed in the IUCN Red List of threatened species³

³ http://www.iucnredlist.org/static/categories_criteria_2_3

and the ongoing discussion for listing of some species in Appendix II of the Convention on International Trade in Endangered Species (Bruckner *et al.* 2003; Conand 2004; Bruckner 2006), there is a need for developing the capacity to collect reliable biological and ecological data. The project also provided new data on the reproduction of several species including the two most highly commercially valuable species *H. scabra* and *H. fuscogilva*, and made specific management recommendations based on these studies (Table 20). However, because species and populations differ (i.e., reproductive cycles, population sex ratios and the size at sexual maturity), information is still needed for individual species in the different countries as well as knowledge on larval dynamics and connectivity. Data on growth, mortality and recruitment of individual commercial species that are key for constructing fisheries models are not available for the region.

There was also a large gap of information on the socioeconomics of the fishery, yet poverty and the associated pressures on the poor are major drivers of over exploitation. Although the project provided new information that increased understanding of the socioeconomics of the fishery, information on many other aspects especially on the factors that affect poor peoples livelihoods and the relationships between these factors, global trade and its impact on livelihoods amongst others, are needed.

Finally, the project also found knowledge gaps in taxonomic and ecological aspects that contribute to biodiversity and ecological knowledge. Some molecular genetics studies have been done on the phylogeny of sea cucumbers including of species in the region (Uthicke *et al.* 2001; Uthicke & Benzie 2003; Uthicke *et al.* 2004; Byrne *et al.* 2010), however, there are several taxonomic queries pending and there is very low capacity for genetic studies in the region. In addition, recent experimental and field studies are providing support for the important role sea cucumbers play in seagrass beds (Wolkenhauer *et al.* 2010), in soft sediments environments where they ameliorate the adverse effects of organic enrichment (MacTavish *et al.* 2012) and in coral reef ecosystems where they buffer changes in pH and therefore have the potential to reduce the impacts of ocean acidification (Schneider *et al.* 2011). However, climate change impacts including increased temperatures and ocean acidification may have a negative influence on sea cucumber populations (Przeslawski *et al.* 2008; Bryne & Przeslawski 2013) and the full impact of this and the compounding effects of fishing pressure is not well understood. The project also contributed to knowledge on the effectiveness of MPAs in conserving sea cucumbers, however, more studies are needed for a thorough understanding of the ecological, social and governance factors that increase effectiveness.

Not only are scientific studies in the identified knowledge gaps needed, closer partnerships between management authorities and the scientific fraternity are needed to help ensure that the scientific requirements for management are met. Efforts to encourage young scientists at local research institutions and universities to conduct MSc and PhD studies in these areas could serve to increase the overall regional scientific skills base and output. Research on regional/subregional patterns and processes in the movement of fishers and products, on species specific abundances across the region, and on governance to understand the conditions that facilitate cooperative management were also recommended during the SCEAM Indian Ocean workshop (FAO 2013).

(3) *Livelihood diversification and alternatives:*

Another challenge facing this fishery is the level of poverty and high dependence on natural resources by coastal communities. This partly drives the continued over exploitation of this fishery. Livelihood diversification and alternative livelihoods initiatives have become popular tools to improve the lives of communities dependent on natural resources. In the region, alternative livelihood initiatives are still in their infancy (Ronnback *et al.* 2002) and their success is highly variable (Ireland *et al.* 2004), although, they are often touted as a means to lift communities out of poverty.

Sea cucumbers are cultured globally for trade, for restocking and for alternative livelihood purposes and in the WIO, sea cucumber culture has been seen as one route to poverty alleviation. In the WIO region, Madagascar has the oldest mariculture project, Tanzania started the research phase in 2010 and Kenya is showing an interest as a consequence of government investment in aquaculture. However, in introducing mariculture as an alternative livelihood or for other purposes, it is important to ensure first that the fishery is effectively managed (Purcell *et al.* 2010). Should a country decide to introduce mariculture, there must be an understanding of the cost-benefits and purpose (restocking, alternative livelihood) of such a venture. In addition, an understanding of the drivers of poverty (socioeconomic, ecological, market) is needed, as well as careful matching of the capacity, needs or aspirations of the targeted community to the initiative. As the sea cucumber mariculture research project in Madagascar has been in existence since 1999, a review of experiences gained in planning and implementation of this project and its offshoots such as the community micro-farms and trade company (Eeckhaut pers. comm.), would be invaluable for other countries exploring the potential of sea cucumber mariculture.

Income diversification initiatives that allow fishers to exit the fishery also have the potential to make the fishery sustainable while providing livelihoods. Private sector mariculture initiatives have the potential to do this by providing employment. In 2012, the Madagascar Holothurie company became a shareholder of a larger venture, Indian Ocean trepang, whose goal is to produce more than 2 million of *H. scabra* per year through aquaculture and farming by 2015 (Eeckhaut pers. comm.). Such an enterprise would be expected to employ local labour potentially increasing the incomes of local communities. Other livelihood diversification projects such as the culture of pearl oysters and milkfish in Tanzania (Ronnbeck *et al.* 2002), and seaweed farming in Zanzibar (Sen 1990; Ronnbeck *et al.* 2002) could provide useful lessons for alternative livelihoods. Finally, another way to increase incomes is by value-addition through improving the quality of the trade product (beche-de-mer). Fishers interviewed during the project indicated a need for training in handling and processing of sea cucumbers as well as training in SCUBA diving. The SCEAM Indian Ocean workshop also identified training for fishers in post-harvesting improvements including the need for a processing guide and training workshops for communities as a priority (FAO 2013). This could be implemented through a series of regional workshops. Countries can also consider mechanisms that encourage fishers to organize into cooperatives that allow them to better negotiate prices and take advantage of microfinance and learning opportunities.

(4) Stakeholder engagement

The importance of stakeholder engagement in fisheries management cannot be underestimated especially in the WIO region where resources are scarce for managing fisheries. There are several reasons for engaging stakeholders; first, they may have information on the resource that is not accessible to management authorities (as noted above), and second, stakeholders have different perceptions, attitudes and socioeconomic conditions that affect the way they react to management decisions. Understanding this would assist in formulating management interventions that are tailored to the local situation and hence that are more likely to succeed. Although there is a cost to stakeholder engagement, in the long-term, the transaction costs of implementation of management decision are reduced. This is because stakeholder engagement increases the probability that a management decision will be accepted. When stakeholders feel they are not sufficiently consulted, resistance and noncompliance often result.

The project showed that there are various opportunities for stakeholder engagement in fisheries management however most countries lacked an overarching engagement framework that could address all the complexities of this and other small-scale fisheries. Some countries may have to amend their fisheries laws to require engagement, most countries did not have a process to ensure accounting and reporting on fisheries levies, or mechanisms for collecting information through stakeholders. Some countries had mechanisms for dialogue with stakeholders such as fishers

councils and beach management committees that though not specific for sea cucumbers could address many of the requirements for engagement for this fishery. An engagement system that details the principles for engagement, the purpose, the process and funding needs could assist countries move towards initiating the implementation of such a system. A useful model for stakeholder engagement is the Fishers' forum that is held annually in Kenya organized by the Wildlife Conservation Society and the Fisheries Department in partnership with representatives from fisher communities (McClanahan *et al.* 2012).

(5) *Marine Protected Areas*

Results from the project showed a higher density and diversity of sea cucumbers in the fully protected areas (no-take) than the fished areas in Kenya, this was also shown in Zanzibar (Eriksson *et al.* 2010) and more recently in the Seychelles (Cariglia *et al.* 2013). Marine protected areas that are managed as no-take zones not only protect biodiversity, they also have the potential to allow sea cucumbers to grow to large sizes increasing fecundity and potential for spill-over into adjacent areas. Community based closures that are in their infancy in the region, have the potential if effectively managed to improve fisheries including of sea cucumbers. The benefits that MPAs confer on this fishery is also not sufficiently recognized in the region so more needs to be done to increase awareness of the fisheries and conservation authorities in the region.

(6) *Regional coordination for management*

A challenge faced by many of the studied countries was the lack of information about many aspects of the trade of sea cucumbers. The studies on the market chain in Kenya, Madagascar and Tanzania, showed that there is not only a direct route to the global market from these countries that was poorly monitored, sea cucumber trade products were also moved from the country of origin to adjacent countries where they were subsequently exported to the international market. An additional challenge was the movement of migratory fishers across borders and fishing illegally and often using illegal gears (Eriksson *et al.* 2012). This challenge can be addressed through better collection and monitoring of trade information as well as regional cooperation in the management of this fishery. Since the fishery is small relative to other fisheries, it would be more cost effective to tackle this issue within the framework of managing other high value fisheries such as octopus that are also traded internationally. The need for regional coordination was also discussed and recommended during the SCEAM Indian Ocean workshop (FAO 2013).

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APPENDIX 1-

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