Marine Pollution Bulletin 83 (2014) 398–407

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Seagrass importance for a small-scale fishery in the tropics: The need for seascape management

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ARTICLE INFO

Article history:
Available online 13 April 2014

Keywords:
Small-scale fisheries
Coastal management
Seascape
Seagrass
Marine spatial planning
MPA

ABSTRACT

Small-scale fisheries (SSF) in tropical seascapes (mosaics of interconnected mangroves, seagrasses and corals) are crucial for food and income. However, management is directed mostly to corals and mangroves. This research analyzes the importance of seagrasses compared to adjacent ecosystems in Chwaka Bay, Zanzibar, Tanzania. Using fish landings; the study investigated: location of fishing effort, fish production (biomass and species), and monetary benefits (aggregated value and per capita income). Seagrasses were the most visited grounds providing highest community benefits. Per capita benefits were equivalent to those from corals and mangroves. All three habitats provided income just above extreme poverty levels; however catches from seagrass appeared more stable. Seagrass are key ecosystems supporting SSF and protection and management are urgently needed. Adoption of a seascape approach considering all ecosystems underpinning SSF and the social aspects of fishing and a shift in emphasis from pure conservation to sustainable resource management would be desirable.

1. Introduction

Small-scale fisheries (SSF) are critical in developing countries, where dependence on natural resources is very high, contributing to food security and income generation. However, to date, management attention to SSF has been low compared to industrial fishing (Mahon, 1997; Mills et al., 2011). Management of SSF is also more complicated as they constitute an occupation, a source of income and a way of life; normally unregistered and unrecognized by management agencies (Chuengpagdee, 2011; Mills et al., 2011). There are several attempts to define SSF, but a universal definition has been difficult to adopt due to their contextual characterization (Berkes et al., 2001). Here we refer to SSF as harvesting activities performed with low technology, self-employed, targeting a wide variety of species and using diverse boats, gears and fishing methods, predominantly performed in developing countries in common situations of insufficient management and *de facto* open access.

SSF in tropical coasts take place along the entire seascape; i.e. the mosaic of interconnected coral reef, seagrass and mangrove ecosystems (Ogden and Gladfelter, 1983; Ogden, 1988). The seascape concept is central to address connectivity between ecosystems and fishers' spatial behavior (Moberg and Ronnback, 2003; IFS/WIOMSA, 2008). Fishers move along the whole coastal zone using the available ecosystems for harvesting activities. However, the spatial dynamics, productivity and value of SSF are still poorly understood (Berkes et al., 2001; Defeo and Castilla, 2005). To redress this, recent work have focused on SSF and the first World Small-Scale Fisheries Congress was held in 2010 (Pomeroy and Andrew, 2011; Jentoft and Eide, 2011; Chuengpagdee, 2011). One key issue is that basic information to understand the contribution of SSF to total catches and their role in poverty alleviation is lacking (Onyango and Jentoft, 2010; Chuenpagdee and Jentoft, 2011). Understanding fishers' behavior, particularly in terms of where harvesting takes place, what species are caught and what habitats are utilized is needed. This knowledge is crucial to create relevant policy and management plans, to promote governance systems which consider fishers' needs and rights (Jentoft, 2011; Allison et al., 2011), and to understand the underlying natural capital sustaining the livelihoods of local communities.

Much attention has focused on assessing coral reef associated fisheries due to their high species diversity and intensive use levels (McClanahan, 2002). SSF are, however, often conducted in seagrass meadows near to shore but the role of seagrasses for these productive activities is often neglected. Orth et al. (2006) argue that the poor charisma of seagrass ecosystems maintains an imbalance between seagrasses and corals, both from a scientific and management perspectives. This bias towards coral reefs is particularly

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http://dx.doi.org/10.1016/j.marpolbul.2014.03.034
0025-326X/

evident in the Indo-Pacific (Unsworth and Cullen, 2010). The lack of attention on seagrasses is surprising given the fact that they have global distribution (den Hartog, 1970; Green and Short, 2003) thus providing substantial ecosystem goods and services. Although their social-ecological importance has been highlighted locally (de la Torre-Castro and Ronnback, 2004), it is only recently that they have been recognized as important social-ecological systems worldwide (Cullen-Unsworth et al., 2014). In addition, the economic value calculated for seagrasses and algal beds is far higher than for corals and mangroves/marshes (Costanza et al., 1997). Even when considering charismatic organisms associated with seagrasses such as manatees, dugongs, sea horses and sea turtles the link between species and their dependence on seagrass ecosystems is seldom made (Hughes et al., 2009). Research about the social importance of seagrass ecosystems is also rare compared to corals, but some studies have stressed their importance for local communities and fisheries (e.g. Bandeira and Gell, 2003; de la Torre-Castro and Ronnback, 2004; Unsworth et al., 2010) particularly in East Africa (Gullstrom et al., 2002; de la Torre-Castro and Ronnback, 2004; de la Torre-Castro, 2006; Nordlund et al., 2010), the broader Indo-Pacific (Unsworth and Cullen, 2010), and Southeast Asia (Fortes, 1988, 1990). Our research adds to these efforts by making a systematic comparison between seagrasses and adjacent ecosystems i.e. corals and mangroves in a local SSF context. Detailed information is provided on catches and monetary value to analyze the fishery at a general level (market aggregated data) and for the individual fishers. Other benefits, such as access and saving fuel are discussed based on previous and parallel research results. To our knowledge, a systematic comparison of the importance of seagrasses and adjacent ecosystems in the tropical seascape has not been done to date.

The research takes a case study approach using Chwaka Bay, Zanzibar, Tanzania, as example. The specific aspects investigated were: (i) SSF spatial dynamics (where fishing effort is directed along the seascape); (ii) fish production (catch biomass and species caught); (iii) economic value (fish catch prices at the local market); and (iv) the importance of the above for the individual fisher (biomass and income per capita depending on the habitat used for harvest). These aspects are used to compare and discuss seagrass importance in the seascape. The research also discusses these aspects from a broader management and social-ecological perspective.

2. Methods

2.1. Study site and SSF in the Chwaka Bay context

Chwaka Bay is located in the East coast of Uŋguja island (hereafter Zanzibar) (6°13′00″–02′54″S and 39°23′38̂–32′00″E; Fig. 1). Seven small villages with a total population of about 10,000 people are situated along the coastline (URT, 2002) (Fig. 1).

Fishing is the most important economic activity in the bay (de la Torre-Castro and Lyimo, 2012). SSF dynamics are complex due to the high heterogeneity of the fisher groups involved, the existence of multiple gears and fishing practices linked to a multifaceted combination of regulations and socio-cultural aspects (de la Torre-Castro and Lindstrom, 2010; de la Torre-Castro, 2012a). SSF take place in a topographically complex sea bed with a tidal regime characterized by large fluctuations and seasonalities caused by the monsoon circulation in the Western Indian Ocean (WIO) (McClanahan, 1996; Tobisson et al., 1998).

The diversity of seagrass species is very high with eleven reported species. The most common species found are *Thalassia hemprichii*, *Cymodocea serrulata*, *C. rotundata*, *Halodule uninervis*, *H. wrightii*, *Thalassodendron ciliatum*, *Syringodium isoetifolium*, *Enhalus acoroides*, and different *Halophila* spp. Seagrasses are spread throughout the whole bay substrate, but are particularly abundant in the West coast in front of Marumbi village (about 5 km north of Chwaka village, Fig. 1). Seagrasses are found in mixed meadows (primarily dominated by *T. hemprichii*, *Enhalus acoroides* and *Cymodocea* spp.) as well as mono-specific in shallow, deep and channel areas. Due to these facts, Chwaka Bay has been considered a hot-spot of seagrass diversity (de la Torre-Castro and Lyimo, 2012).

Fishing takes place daily over the entire area of the bay (about 50 km^2) following seasonal (northeast monsoon, dry season and southeast monsoon) and tidal cycles (semidiurnal; range 1–4.5 m). Due to the heavy burden of fishing activities and tidal constraints, fishers make only one trip per day usually spending about 6 h at sea. On the boat, the fish are threaded with a string to form what is colloquially known as a "batch" (*mtungo*). The "batch" is a collection of fish normally arranged by species which facilitates transportation and selling at the auction. Arriving to the shoreline, the batches are taken directly to the local markets where the fish is auctioned (Appendix I, Supplementary Information). There are only three fish markets in the bay (Uroa – medium size, Marumbi – very small and Chwaka – biggest), fish coming from other villages along the bay's coastline are normally sold in the Chwaka market due to the high number of buyers. The Chwaka village fish market besides being the largest, is the most visited and has a good quality paved road linking straight to the "capital" Zanzibar Town, the number of fish traders found in the Chwaka market is very high as well. Due to the above, all data for this research was compiled there (Fig. 1).

The main fishing gears are wooden basket traps (*dema/madema*), seine nets (*nyavu* refereed here as drag-nets, due to the extended use of the dragging technique, *za kukokota*), handlines and spears (these can be a wooden stick, a metal stick or modern spear guns, *mkuki, kijiti, umangu*).

2.2. Data collection at the local fish market in Chwaka village

Data was collected daily in the Chwaka village fish market during three different sampling periods. This was done considering the time variability produced by the monsoon circulation dominating the whole WIO (Cederlof et al., 1995; McClanahan, 1996; Tobisson et al., 1998). Based on that fact, the data was collected during the northeast monsoon, the dry season, and the southeast monsoon. Fish data was collected using the method specially designed to capture fishery data in the Zanzibar context (Jiddawi and Stanley, 1999; Jiddawi et al., 2002, see Appendix I, Supplementary Information, for details). The northeast monsoon lasts roughly from November to March and data collection took place from November to December 2002 (this period is locally known as *Kaskazi* with "short irregular rains" *Vuli*). The dry season runs from June to August and data was gathered during June and July 2003 (*Kipupwe*). The southeast monsoon lasts from April to October and data collection took place during April and May 2004 (*Kusi* with "long heavy rains" period from March and May, *Masika*). All fish landings sold in the market and brought in the form of "batches" (*mtungo*) were analyzed. For each fishing trip, the following was recorded: time of leaving for fishing (this was determined knowing that fishers start their journey more or less at the same time following the tidal cycles), time of arrival to the market, type of boat, type of gear, bait used, catch weight, final auction price, species composition (common species and others), number of fishers per boat, and fishing habitat visited (local fishing grounds dominated by mangroves, seagrasses or corals) (see Appendix I, Supplementary Information, for data collection sheet). All data was recorded at the market and photographs were taken for back-up information. When the auction closed, the research team gathered at the local research station to check the data collection sheets to ensure that the

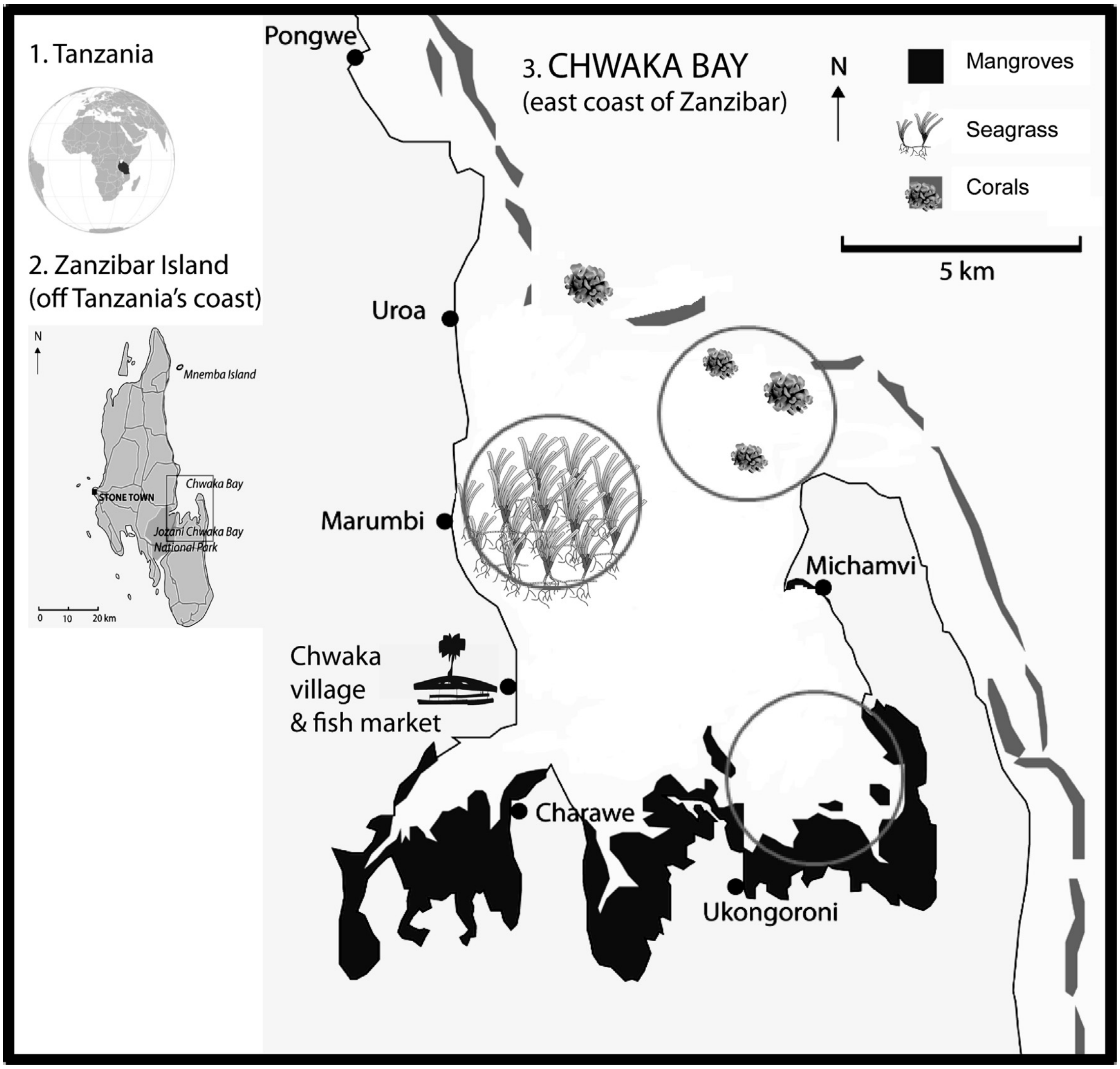

Fig. 1. Study site. Chwaka Bay, Zanzibar, Tanzania (6°13′00″–02′54″S and 39°23′38″–32′E), showing the seascape habitats considered in the study (seagrasses, corals and mangroves). The circles show the areas from where fish catches were analyzed. Black dots are the villages along the coast. All fish catches arriving to the local market in Chwaka village (the largest in the bay) were analyzed at three different times (northeast monsoon, dry season and southeast monsoon). Figure adapted from Jiddawi and Lindstrom (2012). Symbols courtesy of Integration and Application Network, University University of Maryland.

information was legible and accurate. This market study was part of a larger effort to understand the role of seagrasses in Zanzibar and in the WIO. Other studies using interviews were done to gather information about the overall role of seagrasses for the local communities in Chwaka Bay (e.g. de la Torre-Castro and Ronnback, 2004; de la Torre-Castro, 2006; de la Torre-Castro et al., 2008). Information from these works has been used here to broaden the understanding and discussion, but in this particular study the main focus is on the importance of seagrasses compared to adjacent ecosystems based on fish market information.

2.3. Data analyses

Meteorological conditions occurring when data was collected were checked to rule out anomalous events (e.g. El Niño, severe storms, etc.). The number of days for the analysis considered in each sampled time was adjusted to be able to analyze data series of the same length in the three different times when data was collected. This was set according to the number of days in a lunar month (i.e. irrespective of the original length, the data set for each sampled time was reduced to 4 weeks covering from new moon to new moon). Satellite pictures and underwater photos were used to select the areas in the bay representing the different habitats i.e., mangroves, seagrasses and corals. The three selected areas representing mangroves, seagrasses and corals were about the same size (≈7 km^2) (Fig. 1). The delimitation of the different fishing grounds in the bay was also mapped in parallel studies (Bergstén, 2004; Hammar, 2005); all fishing grounds reported by fishers that were among the selected areas were considered in the analysis. From all information obtained in the market data collection sheets the following was selected and/or computed for further statistical analysis: CPUE (catch per unit effort) was similar for all boats since the fishers use the tidal circulation to facilitate navigation, this was about 6 h at the sea which is equivalent to one fishing trip. Boat type correlated with gear used and was ruled out for further analysis and bait was not considered since it was not recorded for all gears known to use bait. The rest of the variables were used further (see below).

Descriptive statistics were used to illustrate the main fishing features in each habitat (number of fishers harvesting in each habitat, fish catch weight, economic value of the fish catch, fishing pressure and dominating gears) (Table 1). The spatial distribution

Table 1
Chwaka village fish market aggregated data for all the habitats and times (northeast monsoon, dry and southeast monsoon) sampled in the study.

	Corals	Seagrasses	Mangroves
Total catch (kg)	12031.6	46409.6	11810.5
Total economic value (TZS)	9551820.0	32358590.0	8837680.0
Total number of fishers (individuals)	2653.0	11308.0	2991.0
Northeast monsoon	1035	2724	780
Dry	538	4067	1131
Southeast monsoon	1080	4517	1080
Fishing pressure (no. fishers km^2 day^{-1})	13.53	57.69	15.26
Dominating gears in%			
Basket traps	30.6	29.8	16.14
Drag-nets	31.8	34.15	43.65
Spear	23.5	12.8	29.98
Handline	10.4	21.7	4.45
Other nets	2.65	0.22	1.8
Unknown	1.00	0.18	0.00
Uzio/wood fences	–	1.0	3.78
Hands only	–	0.07	–

of the fishers in the different habitats was determined by counting the number of fishing trips done to the different selected areas i.e. mangroves, seagrasses and corals (Fig. 2). Total catches (fish fresh weight) and total economic value (fish price in the auction) for each habitat and sampled time (season) were computed. Since the data distribution was skewed for fish biomass (kg^1 fisher^{-1} day^{-1}) and income (TZS^1 fisher^{-1} day^{-1}) per capita median values, and minimum and maximum were calculated in addition to the mean and standard deviation to gain an accurate picture of the fishery situation. The data was graphically illustrated using boxplots (Figs. 3 and 4). Two boxplot graphs were created to visualize the variation in fish biomass (kg^1 fisher^{-1} day^{-1}) and income (TZS^1 fisher^{-1} day^{-1}) for all different gears, habitats and seasons. Through the graphs data dispersion for each gear, habitat and time was obtained (IQR = Interquantile range = size of the box), together with median, minimum value, maximum observation (below upper fence), and points falling outside the maximum observation (see Appendix II, Supplementary Information, for interpretation of the boxplots used in this study).

Two linear models were used to investigate how fishing in the different habitats may affect the individual fisher (one in terms of obtained fish kg^1 fisher^{-1} day^{-1} and the other in terms of income TZS^1 fisher^{-1} day^{-1}). These analyses were done considering three key variables, i.e. gear, habitat (where fishing took place) and time

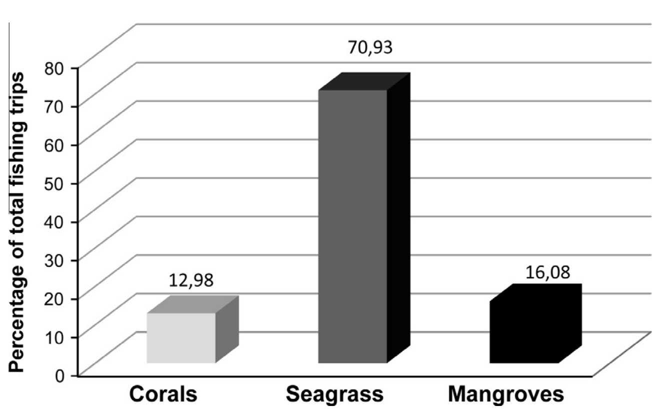

Fig. 2. Habitats used by local fishers in the seascape of Chwaka Bay, Zanzibar, Tanzania. Percentage of the total fishing trips to the different areas during the three sampled times, i.e. northeast monsoon, dry season and southeast monsoon.

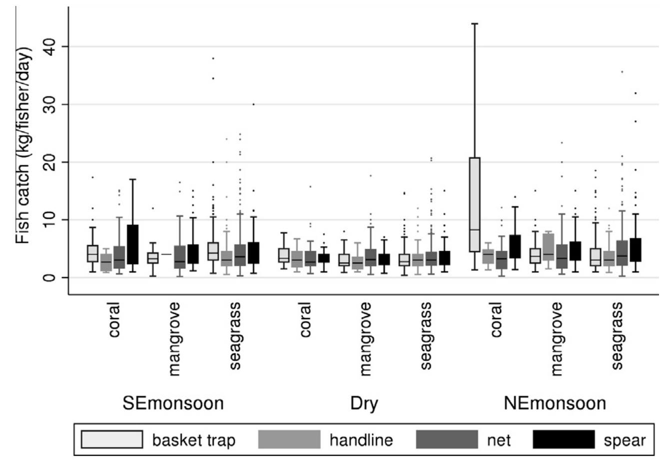

Fig. 3. Boxplots for fish catch biomass per capita (kg^1 fisher^{-1} day^{-1}) for the three times sampled, gears and habitats. Unit effort is one day of work (about 6 h at sea). The size of the box shows data dispersion (Interquartile range = IQR). The horizontal line in the box is the median value. Upper box level = 75th percentile (upper quartile), lower box level = 25th percent percentile (lower quartile). Separate points are values beyond the upper fence. Bars show the minimum and maximum (below 1.5 * IQR) values (see Appendix II, Supplementary Information).

(northeast monsoon, dry, southeast monsoon). Two 3-way ANOVAs with the above variables and their respective interactions were performed; one for biomass and one for income (Appendix III, Supplementary Information). When significant differences occurred ($p < 0.05$) the Bonferroni correction (BC) was applied to determine the final significant differences between habitats. For each ANOVA pairwise tests were performed summing up to 72 pairwise tests totally (Appendix III, Supplementary Information). The significance level for the pairwise tests was determined by the critical p-value based on the BC, i.e. 0.05/36 = 0.00139. To better fulfill the ANOVA assumptions on normality and variance homogeneity the analysis was performed on log-transformed values. All the statistical analyses were performed with the statistical program Stata version 12.

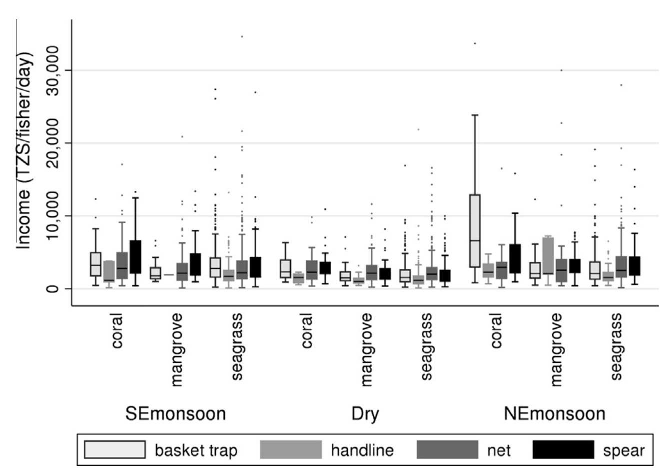

Fig. 4. Boxplots for income based on fish price at the local market auction (TZS^1 fisher^{-1} day^{-1}) for the three times sampled, gears and habitats. Unit effort is one day of work (about 6 h at sea). The size of the box shows data dispersion (Interquartile range = IQR). The horizontal line in the box is the median value. Upper box level = 75th percentile (upper quartile), lower box level = 25th percent percentile (lower quartile). Separate points are values beyond the upper fence. Bars show the minimum and maximum (below 1.5 * IQR) values (see Appendix II, Supplementary Information). 1TZS = 0.0009USD.

Table 2
Top five dominating fish species identified in Chwaka village fish market in the different times (seasons) during the sampled period.

Time 1 northeast monsoon	% Of total	Time 2 dry season	% Of total	Time 3 southeast monsoon	% Of total
Scarus ghobban	16.5	*Siganus sutor*	22	*Siganus sutor*	20.3
Siganus sutor	15.4	*Parupeneus macronema*	11.7	*L. vaigiensis*	15.0
Lethrinus mahsena	10.2	*Scarus ghobban*	11.45	*Scarus ghobban*	10.4
Lethrinus lentjan	7.6	*Leptoscarus vaigiensis*	11.3	*Lethrinus lentjan*	10.1
Leptoscarus vaigiensis	7.4	*Lethrinus lentjan*	8.4	*Lutjanus monostigma*	7.6
Sum top-five species	57.1		64.8		63.4

Fish species composition was calculated using the relative abundance of the species found in each "batch" brought to the market belonging to the selected three habitats, i.e. mangroves, seagrasses and corals. Data was then aggregated by time (season) and pooled for all habitats to determine the most common species found in the bay. This analysis, although lacking details, provides a clear indication of what type of fish dominates the catches in Chwaka Bay (Table 2).

The study limitations are acknowledged in the sense that only the biggest market in the bay was sampled and that there is no replication over time. However, the choice was based on the fact that the Chwaka market is the largest and most important within the bay but also in Zanzibar where seagrass associated fish is very common in catches for the whole Island (DFMR, 2007). Spatial replication is considered acceptable since we are using a case study approach and each area dominated by the particular habitat within the bay was composed of numerous fishing grounds. All these grounds were mapped and all fish harvested in those areas was sampled (see above). The restrictions in sampling were due to logistical reasons since sampling in these rural developing areas is highly resource demanding. However, the results are considered reliable and valid enough to illustrate the arguments and to promote better management.

3. Results

3.1. General market data and SFF spatial dynamics (where fishing effort is directed)

The data analysis showed that fishing takes place in the three investigated habitats (mangroves, seagrasses and corals) in Chwaka Bay (Table 1, Fig. 2). However, compared to mangroves and coral dominated fishing grounds, seagrass dominated grounds were the most visited places for fish harvesting (Fig. 2). The dominating gears in the area were basket traps, drag-nets and spears. The fishing pressure (No. fishers km^{-2} day^{-1}) varied a lot between the three habitats, but with seagrasses showing the highest (Table 1, Fig. 2).

3.2. Aggregated fish production and economic value in the three different habitats

Total catch biomass in the different habitats varied a lot as well. The data shows that seagrass habitats provided the largest amount of fish and economic value (catch prices at the local market auction) as well as the largest catches in the bay (Table 1). While mangroves and corals had about the same production levels; seagrasses were about four times higher with the economic values following the same pattern (Table 1).

3.3. Dominating fish species harvested in Chwaka Bay

The analysis of fish species composition revealead that in all the investigated times (northeast monsoon, dry season and southeast monsoon) the dominated fish caught in the bay was seagrass associated fish (i.e. fish species that depend on seagrass meadows in one way or another at least during one part of their life cycle). The top-five dominating species in the different times (seasons) belonged to the following families: Scaridae, Siganidae, Lethrinidae, Lutjanidae and Mullidae. The detailed information on common species for the three sampled periods is shown in Table 2.

3.4. Importance of fishing habitat choice from the individual fisher's perspective

The fishing situation was pictured with gear used, habitat chosen for harvesting and when the activity took place. Figs. 3 and 4 show boxplots illustrating the catches and income per capita per day illustrating the relative importance of each habitat. The data shows that catches in general were small (less than 10 kg^1 $fisher^{-1}$ day^{-1}) and that differences between small and large catches were rare (Fig. 3). However, relatively larger catches were found in both corals and seagrass habitats, particularly when fishing with basket traps in corals during the northeast monsoon and in seagrasses during the southeast monsoon. The income level results follow, more or less, the same pattern as the one described for biomass (Fig. 4).

3.5. Differences for the individual fisher related to gear type and habitat choice

In this section a description of the main results for income and biomass per capita is presented. The detailed results of the 3-way ANOVAs are presented in Appendix III, Supplementary Information. Table 3 (Supplementary Data) shows the basic statistics for each gear, time (season) and habitat. Table 4 (Supplementary Data) shows the p-value results of the two 3-way ANOVAs and the subsequent significant pairwise tests based on the BC for both catch biomass (kg^1 $fisher^{-1}$ day^{-1}) and income (TZS^1 $fisher^{-1}$ day^{-1}).

3.6. Basket trap fishers (dema/madema)

Fishers using basket traps harvested the largest catches and revenues in the whole study and they were obtained mainly from seagrasses and coral habitats (Table 3, Supplementary Data; Fig. 3). The minimum and maximum values for biomass were 0.25–44 kg^1 $fisher^{-1}$ day^{-1} (median biomass range: 2.5–8.25 kg^1 $fisher^{-1}$ day^{-1}; mean biomass range: 2.61–8.99 kg^1 $fisher^{-1}$ day^{-1}). Income values varied a lot from a minimum of 200 – to a maximum of 33,700 TZS^1 $fisher^{-1}$ day^{-1} (0.18–30.33 USD); with a median income range of 1500–6600 TZS^1 $fisher^{-1}$ day^{-1} (1.35–5.9 USD) and a mean income range 1545–6149 TZS^1 $fisher^{-1}$ day^{-1} (1.39–5.53 USD). Particularly large catches were found when fishing in coral areas during the northeast monsoon (Fig. 3) and thus income was highest (Fig. 4).

3.7. Drag-net fishers (nyavu za kukokota)

For this group the highest catches were obtained from fishing over seagrass beds. In terms of income, good revenues were obtained when fishing in both seagrass and coral habitats (Figs. 3 and 4). Biomass extremes varied a lot with a minimum value of 0.18 kg^1 $fisher^{-1}$ day^{-1} to a maximum of 35.66 kg^1 $fisher^{-1}$ day^{-1}. The median ranged little from 2.75 to 3.68 kg^1 $fisher^{-1}$ day^{-1}, but not the mean 0.66–3.66 kg^1 $fisher^{-1}$ day^{-1}. Income minimum and maximum range was from about 130 to 34,666 TZS^1 $fisher^{-1}$ day^{-1} (0.11–31.19 USD); with a median range of 2000 to about 3000 TZS^1 $fisher^{-1}$ day^{-1} (1.80–2.70 USD) and mean range from 1926 to 2762 TZS^1 $fisher^{-1}$ day^{-1}. (1.733–2.48 USD). The highest variability in both biomass and income was associated with rainy seasons when fishing in mangrove areas (Table 3, Supplementary Data; Figs. 3 and 4).

3.8. Handline fishers (mshipi)

Biomass minimum and maximum were 0.5–24 kg^1 $fisher^{-1}$ day^{-1} respectively; with a median range from 2.5 to 4 $kg^1 fisher^{-1}$ day^{-1} and a mean of 2.23–4.15 kg^1 $fisher^{-1}$ day^{-1}. Income median varied from 1000 to 2266 (0.90–2.03 USD) TZS^1 $fisher^{-1}$ day^{-1}, with a minimum of 100 TZS^1 $fisher^{-1}$ day^{-1} (0.09 USD) and a maximum of 21,900 TZS^1 $fisher^{-1}$ day^{-1} (19.70 USD), while the mean ranged from 1064 to 2706 TZS^1 $fisher^{-1}$ day^{-1} (0.95–2.43 USD) (Table 3, Supplementary Data; Figs. 3 and 4). Variability for this group was highest during rainy seasons.

3.9. Spear fishers (mkuki, kijiti)

The minimum–maximum biomass range for this group was 1.00–31.91 kg^1 $fisher^{-1}$ day^{-1}; with a median ranging from 3 to 4.75 and a mean of 2.88–4.87 kg^1 $fisher^{-1}$ day^{-1}). The income levels varied from 255 to 27,000 TZS^1 $fisher^{-1}$ day^{-1} (0.22–24.30 USD); with a median range of 1695–3633 and a mean of 1685–3473 TZS^1 $fisher^{-1}$ day^{-1} (1.52–3.26 USD; 1.51–3.12 USD respectively). Variation for both biomass and income was found when fishing in corals in the long rainy season (southeast monsoon) (Table 3, Supplementary Data; Figs. 3 and 4).

3.10. Significant differences for catch biomass and income per capita

The results of the 3-way ANOVA for both biomass and income showed significant values for all the main factors tested and their interactions. However, the subsequent 72 pairwise tests showed only four (4) significant values (Table 4, Supplementary Data). The strongest significant values were found for basket trap fishers during the northeast monsoon between coral and seagrass habitats ($p < 0.00139$) and between coral and mangrove habitats ($p < 0.00139$). For income, the same pairwise tests were significant; between coral and seagrass habitats ($p < 0.00139$) and between coral and mangrove habitats ($p < 0.00139$) (Table 4, Supplementary Data). All the other 68 values were not significant at all (Appendix III, Supplementary Information).

4. Discussion

4.1. The importance of seagrasses for SSF

The results of this study show that seagrasses play an important role for SSF in Chwaka Bay, and we suggest that this finding is likely applicable to other similar tropical coastal systems. Seagrass dominated areas were by far the most preferred fishing grounds by the local fishers, providing large catches, high revenues and significantly contributing to food and livelihood security (Table 1, Fig. 2). Moreover, fishing in different habitats and with different gears was not significant for the vast majority of the pairwise comparisons (Table 4, Supplementary Data; Appendix III, Supplementary Information). This means that irrespective of where a person fishes, what gear is used and during what season, the harvested catches are more or less the same on a per capita basis. A striking result from this study is that fishing pressure on the seagrasses is so high (Table 1), and still the meadows are poorly considered in fisheries management (de la Torre-Castro, 2012b). Parallel interviews with local fishermen reported that they consider seagrasses as "an excellent" fishing ground, both for catch abundance and accessibility (de la Torre-Castro and Ronnback, 2004). Fishers acknowledged seagrasses for saving effort due to the proximity to shore as well as less need for engine fuel. When it comes to what type of fish that dominates catches in the bay, more than 50% of the dominant fish species landed in the Chwaka Bay market were seagrass associated species (Table 2). These results are very similar to those reported by the Department of Fisheries and Marine Resources (DFMR) in Zanzibar that keeps records of the catches from the different local markets. In order of importance, the following families are given by the DFMR Siganidae, Scaridae, Lethrinidae, Serranidae and Mullidae (DFMR, 2010). The dominance of seagrass associated species in catches has been observed not only in Zanzibar, but also in other places of the WIO such as Kenya (McClanahan and Mangi, 2001; Mangi and Roberts, 2007; Hicks and McClanahan,2012), Mozambique (Gell and Whittington, 2002; Bandeira and Gell, 2003) and Madagascar (Laroche and Ramananarivo, 1995; Davies et al., 2009), although most of the time they are referred to as "coral reef fisheries" (Unsworth and Cullen, 2010).

The findings in this study challenge the common belief that coral reefs are the most important fishing grounds in tropical systems. The results show how important fish catches are derived from seagrass and mangrove habitats as well, which in turn provide communal and individual benefits. The catches and income per capita obtained from seagrasses were in the same order of magnitude as those from corals and mangroves (Figs. 3 and 4). In general, most of the catches landed in Chwaka Bay market were small (0–10 kg^1 $fisher^{-1}$ day^{-1}) for all habitats over the three sampled times (seasons). The study provides a robust test showing that there are no significant differences between fishing in one or other habitat, and this is true irrespective of gear used (Table 4, Supplementary Data). As a result, fishermen prefer to fish in closer seagrasses as they may consider this as the best cost-effective option, balancing fishing effort and gain. Weather and the monsoon circulation may also play a role, as mangroves and coral reefs are more difficult to access during rainy seasons and windy days. Thus, it can be argued that compared to the other ecosystems, seagrasses provide advantages in terms of accessibility, safety and productivity.

For the whole study only one feature stands out – basket trap fishers fishing in coral habitats during the northeast monsoon (Fig. 3). Significant values were found for both catch biomass and income (Table 4, Supplementary Data; Figs. 3 and 4). Interview studies have shown that basket trap fishers in Chwaka Bay have a higher income per day compared to others (de la Torre-Castro and Ronnback, 2004) and the present study confirms the previous findings. Nevertheless, basket trap fishers have previously reported a preference for seagrass habitats; but large catches from coral habitats are possible to obtain since adult abundance is normally higher in coral areas than in seagrasses due to the nursery function of the latter; some fish may also prefer deeper waters found in coral environments (e.g. Cocheret de la Moriniere et al., 2002). In addition, fishers explained that during the northeast monsoon lots of fish move inside the bay for shelter and catches tend to be very good. The relative gains from the coral environment are, however, restricted to *only one season and one gear*, with the boxplot showing an extremely high data dispersion (Figs. 3 and 4). Since we do not have time replication it is necessary to replicate this study to confirm this finding.

From an economic perspective the income generated by SSF is crucial for the household economy in Chwaka Bay (de la Torre-Castro, 2006). Livelihood diversification analyses in the surrounding villages of the bay show that fishing is still the primary source of income (de la Torre-Castro and Ronnback, 2004; de la Torre-Castro, unpublished data). However, this SSF provided generally low income. Most income values fall very close to the extreme poverty line. The definition of "extreme poverty" was set as all income below 1 USD day^{-1} when the data was collected (UNDP poverty line index); nowadays, UNDP has increased the value to 1.25 USD day^{-1}. The income data show that the median income ranged between 0.9 and 5.94 USD fisher^{-1} day^{-1}. These low values show that irrespective of which habitat is used for fishing the population remains to a large extent in poverty. However, it is important to point out that the economic data in this study refers to gross income only, based on the fish prices at the market auction. The advantages of fishing in seagrass habitats in terms of, for instance, fuel and effort savings were not accounted for and thus total net income per capita was not calculated. Such calculation would most probably increase the relative value of seagrass habitats. The dispersion of the data (Figs. 3 and 4) provides an indication of catches variability which in turn can be related to a steady flow of income over time. The largest IQR and SD for all data were found for corals (Table 3, Supplementary Data; Figs. 3 and 4); and even the maximum income obtained from corals is very low (about six dollars per day in the northeast monsoon fishing with traps) (Table 3, Supplementary Data; Figs. 3 and 4). For handline and spear fishers, rainy seasons seem to increase variability when fishing also in coral habitats. Fishing in mangroves showed the largest range during the northeast monsoon. Fishing in seagrasses also, presented some variability and outliers in fish catches, especially during the southeast monsoon for net fishers, but in general they were relatively stable (Fig. 3). The influence of the different seasons on the dynamics of the WIO is well established (McClanahan, 1996) and the variation according to the sampled times may reflect that. Local fishers have learnt through generations how to deal with the changing conditions and how to make use of the tides and winds when fishing (Tobisson et al., 1998). The relative closeness of seagrass meadows can be an important factor for fishing preference during harsh conditions. As one fisher expressed it *"Why travel further if I can obtain good catches in the seagrasses?"* Another aspect is the prohibition to fish in the mangrove creek in the southwest part of the bay closest to Chwaka village (de la Torre-Castro and Lindstrom, 2010).

4.2. Policy and management implications

MPAs are widespread management tools, however, their global efficiency has been questioned (Hilborn, 2013); and their usefulness in tropical contexts have been long debated due to the human resource dependence, the low enforcement capacities and the high levels of conflicts that arise when prohibiting fishing (e.g. Christie, 2004; Cinner, 2011). In addition, seagrasses have not been considered in MPA design as a valuable feature on their own. They are normally relegated as an ordinary part of the coral reef mosaic. Due to that, seagrasses have been considered "free riders" in conservation programs in the WIO (Gullstrom et al., 2002). The tendency to focus on coral management and conservation (Orth et al., 2006) at the expense of other key ecosystems, produces a misfit between the institutions created, the ecological features (i.e. all seascape ecosystems are connected and ecologically important) and people's *de facto* behavior (fishers move and fish along the whole seascape, not only in coral habitats). The "problem of the fit", basically matching ecosystem properties with the management regime attributes, is one of the key problems hindering management advances. There should be congruence between the biophysical component and its dynamics and the institutions created to manage human activities (Berkes and Folke, 1988; Young, 2002).

Here, it is argued that SSF management will benefit from applying a seascape approach and explicitly paying attention to seagrasses. In this way, the present institutional misfit can be reduced. In the case of Tanzania, lack of knowledge and integration of critical factors underpinning fish production have led to partial management initiatives (see also Unsworth and Cullen, 2010). In Zanzibar, policy documents for marine management stress MPAs as well as coral and mangrove conservation (e.g. Ruitenbeek et al., 2005). In Chwaka Bay management efforts and economic resources (coming from external donors) have historically been directed to mangrove conservation (RGZ, 2004; Saunders, 2011; Lugomela, 2012) leaving the oceanic part unattended (de la Torre-Castro 2012a, 2012b). Recent management plans for the bay have added coral protection; regrettably still missing the seagrasses and lacking a holistic and integrative approach (DFMR/MIMCA, 2010; Gustavsson et al., 2014). The results of this study suggest that these types of initiatives will most probably fail since there is a clear mismatch between the ecological features, the SSF dynamics and the proposed management.

4.3. Spatial dynamics shifting fishing pressure to seagrass habitats

The asymmetry in management efforts not addressing the whole seascape has created a serious situation. High fishing pressure takes place on seagrass habitats (Table 1). The fishing pressure found for Chwaka Bay is similar to that reported for other regions in the WIO (e.g. Kenya, McClanahan et al., 2008); however, the fishing pressure on seagrass areas is about four times higher than for corals and mangroves with the dominating gear being drag-nets. These nets and the dragging technique damage the meadows through up-rooting and fragmentation. Since it is not known at what intensity levels fisheries may produce cascading trophic effects and finally affect seagrasses structure (Valentine et al., 2008), a precautionary approach is advisable. Gullström et al. (2006) found that the seagrasses in Chwaka Bay have been relatively stable during a 20 year period, but local gains and losses were found. They co-occurred with intensive human use due to fishing and seaweed farming of red algae. In addition, there is evidence showing that heavy fishing pressure that removes sea urchin predators (e.g. trigger fish), can cascade resulting in high densities of sea urchins that decimate seagrass beds through overgrazing (de la Torre-Castro and Jiddawi, 2005; Eklöf et al., 2008). A severe decrease of herbivores like the "seagrass parrot fish" (*Leptoscarus vaigiensis*) may promote epiphyte increase, theoretically altering the rates of seagrass productivity (de la Torre-Castro et al., 2008). The multiple pressures over ecosystems in the bay have created a situation in which the nursery grounds are heavily used and intense juvenile removal takes place, while fish adult biomass is constantly removed from corals diminishing potential spawning stocks (de la Torre-Castro and Ronnback, 2004). This causes both growth and recruitment overfishing to be present. Growth overfishing occurs when fish are harvested before they have time to fully realize their growth potential and recruitment overfishing when diminishing the chances and ability of fish to reproduce, leading to radical reductions of young entering the system (Pauly, 1988; Froese, 2004). The fishery seems to be in an intermediate level of exploitation. At this level predators such as groupers and snappers decrease and there is a domination of mixed catches with emperors, goat fish and parrot fish. A severe damaged fishery would show a total domination of herbivores such as rabbit fish (Jennings and Lock, 1996).

4.4. Looking forward: connectivity and social dimensions within the seascape

The "seascape approach" initiated in the mid-1970s and early 1980s (Ogden and Gladfelter, 1983; Ogden 1988) is gaining momentum with a steady increase of publications from the 1990s and onwards. In Chwaka Bay, some aspects related to the seascape have been studied. Connectivity and the nursery importance have been reviewed for the bay (Gullström et al., 2012). At seascape level it has been shown that Chwaka Bay houses significantly higher densities of fish due to the presence of mangroves (Dorenbosch et al., 2006). Habitat segregation among fish species was also found with some fish species exclusively observed in seagrasses (Dorenbosch et al., 2005; Dorenbosch et al., 2006).

Gullström et al. (2008) found that the meadows in the bay are highly diverse and their structural features affect fish assemblages. Lugendo et al. (2005) showed that commercial species are very common in seagrass beds. *Siganus sutor* (Rabbit fish) having the highest abundance in seagrasses. This species is crucial as staple food for locals. Seagrasses are directly consumed by "seagrass parrot fish" (*L. vaigiensis*) which is another key species for food security in the area (de la Torre-Castro et al., 2008; Gullström et al., 2011). In addition fish diversity was highest in seagrasses compared to mangroves and mud/flats (Lugendo et al., 2007). An analysis of seagrass importance for food provisioning services (i.e. as food for fish) showed that most food items consumed by commercial fishes are associated with seagrasses and bait for SSF fisheries is collected in seagrass intertidal areas (de la Torre-Castro et al., 2008). Numerous fish species are generalists using different habitats. Multiple habitat use is thus central (Nagelkerken et al., 2000; Berkström, 2012) including changing dynamics in diurnal and nocturnal fish behavior and movement. For instance, coral reef fishes are proven to migrate to seagrasses during night for feeding (e.g. Roblee and Zieman, 1984) and economic important species, such as snappers present multiple habitat use (e.g. Luo et al., 2009). These are strong arguments for considering all critical habitats for fish along the seascape when designing policy guidelines, management plans and institutions that fit the ecological conditions.

The major challenge is to add the social dimensions to the seascape analysis, i.e. the social reasons behind fishers' habitat preference, fishing pressure variation as well as cultural aspects driving the spatial dynamics of resource use. This will provide the basis for a better understanding of SSF and to create relevant management. Social-ecological "lenses" are necessary to understand what is going on, to create adaptive responses and to frame better sustainable futures (Perry et al., 2011). We strongly encourage the adoption of a seascape approach to break the problem of the institutional misfit in these tropical contexts. The seascape approach has been successfully used as analytical framework to address fisheries' problems in other developing countries (Gallardo, 2008) as well as in the WIO (Crona, 2006).

We suggest that a shift towards better SSF policy and management should contemplate the following elements: (i) consideration of all the key ecosystems underpinning a fishery; (ii) a comprehensive spatial analysis in which fishers' movements and habitat used for harvesting is addressed; (iii) consideration of connectivity (ecological, genetical, physical and biogeochemical); (iv) a holistic approach bearing in mind the embeddedness of humans in nature and; (v) merging the seascape approach with on-going management initiatives.

The much needed shift in policy and management will be extremely difficult if it does not take into account on-going efforts. The "seascape approach" should thus be considered as a complement to other initiatives and not as a pure substitution (IFS/WIOMSA, 2008). It is becoming clear in fisheries management that only combined approaches will produce better outcomes (Pitcher and Cheung, 2013). Hybrid approaches have also been proposed as the way forward in the WIO (Aswani et al., 2012). Since this study is based on a specific case, it is advisable to perform similar studies in other regions and habitats to further understand SSF dynamics in relation to habitat use.

5. Conclusion

This case study has illustrated the dynamics of SSF in a tropical area with a seascape comprising mangroves, seagrasses and corals. The differences in benefits obtained from the various habitats and times sampled were very small when it comes to daily catches and gross income per capita; however, seagrasses provided the highest aggregated benefits for the community. On a per capita basis, seagrasses provided benefits in the same order of magnitude as the other ecosystems. In addition, seagrasses were the most frequent fishing sites, suggesting an advantage in terms of access, saving energy, fuel and stability in catches. Hitherto, the importance of seagrasses has been overlooked in policy and management. The study strongly argues for a shift in management approach considering all key ecosystems underpinning fisheries productivity and fit the dynamics of SSF. Such an approach will include seagrasses explicitly, add social dimensions and consider seascape connections. Policy and management in marine resource dependent areas where SSF are a key component of the social-ecological system should move from pure conservationist approaches focusing on single ecosystems to promote proper solutions for sustainable SSF and associated livelihoods.

Acknowledgements

The authors are thankful for the support given by the DFMR, the Institute of Marine Sciences and WIOMSA in Zanzibar. The group discussions held at the Department of Systems Ecology, Department of Political Science and Stockholm Resilience Center at Stockholm University contributed to enhance the study. Thanks to Rashidi Banzi, Salum Hashim and Hamadi Khatibu for their significant inputs in the field. To Maria Bergstén and Linus Hammar for their important contributions digitalizing the market data and mapping the fishing grounds. Thanks to Ratana Chuenpangdee and the "Too Big to Ignore" network for sharing aspects of small-scale fisheries. Thanks to Dr. Lars Lindström for field assistance and for patiently reading the manuscript and to Jan-Olov Persson for invaluable statistical advice. Our gratitude goes to two anonymous reviewers and one guest editor who provided sharp and appreciated comments to enhance this manuscript. This study was financed by Sida, Swedish International Development Cooperation Agency and VR, Swedish Research Council (344-2011-5448).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2014.03.034.

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