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INVITED EDITORIAL

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Integrating Resource Perception, Ecological Surveys, and Fisheries Statistics: A Review of the Fisheries in Zanzibar

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ABSTRACT
Most tropical small-scale fishing communities, like those of Zanzibar (Tanzania), strongly depend on fisheries resources for income and protein supply. Although imperative, the evaluation of fisheries performance indicators for adequate management is often challenging given the data-poor nature of most of these fisheries. This study reviews the current literature and integrates findings from annual fisheries statistics, the perceptions of fishers, and ecological surveys to provide a holistic understanding of the fisheries exploitation level in Zanzibar. Most reviewed studies focused on the perception of fishers and ecological surveys, and only a few conducted any form of fisheries assessment. While the perception of fishers suggests resource overexploitation, officially reported catch data rather suggest a state around full exploitation for most resources. Ecological surveys indicate overexploitation of several target fish stocks for the west coast of Unguja Island. This study indicates that the perception of fishers and aggregated catch statistics should not be used as the only source of information when assessing data-poor, multispecies fisheries. Furthermore, indicators from ecological surveys should be compared to reference points and related to fishing effort to inform fisheries managers better. The here used approach highlights that integrating local knowledge, fisheries-dependent and independent information helps to identify areas and taxonomic groups of highest concern and guides future research efforts toward contributing better information for the management of data-poor fisheries.

KEYWORDS
Zanzibar; small-scale fisheries; fisheries assessment; ecological indicators; integrated assessment

1. Introduction

Small-scale fisheries worldwide employ over 90% of capture fisher (FAO 2015) and are the principal livelihood and protein suppliers in many coastal communities around the world (Allison and Ellis 2001; Chuenpagdee 2011). Particularly in the Western Indian Ocean region (WIO) fisheries resources can provide up to 70% of animal protein and fisheries often employ more than 50% of the local population (van der Elst et al. 2005; Walmsley et al. 2006; Jiddawi 2012; Barnes-Mauthe et al. 2013; McClanahan et al. 2015). This high dependency under a steadily increasing population density and the lack of alternative livelihoods in many coastal communities underlines the prime importance of the management of small-scale fisheries (Drammeh 2000; Walmsley et al. 2006; McClanahan et al. 2008; Najmudeen and Sathiadhas 2008; Jacquet et al. 2010; Nordlund et al. 2014). Furthermore, this strong dependency makes coastal communities highly vulnerable to the implementation of restrictive management measures. Mismanagement can lead to distrust between fisheries authorities and fishing communities and can weaken compliance with management measures (Boonstra and Bach Dang 2010).

The small-scale fisheries in the WIO region are mainly multigear and multispecies fisheries that are carried out mostly in the nearshore areas (Gell and Whittington 2002; Jiddawi and Ohman 2002; Samoilys et al. 2011). The use of conventional output control measures (e.g., quota systems) is highly challenging in such fisheries given the lack of financial and institutional capacity for monitoring and enforcing them for a multitude of species (Salas et al. 2007; Pomeroy 2012). This is amplified by the adaptive behavior of fishers in space, time, and fishing method (e.g., Wiyono et al. 2006; Daw 2008) together with the lack of well-defined landing ports (Mills et al. 2011). Small-scale fisheries managers,

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thus, strongly rely on input measures such as gear-type and effort control as well as temporal and permanent closures of important habitats. The control of gear-specific or overall effort and the closure of fishing grounds are highly sensitive management actions, since effort reduction or gear restrictions can lead to the loss of livelihoods and ultimately to increased food insecurity (Diegues 2008; Salayo et al. 2008; Cinner et al. 2012). The consequences of data uncertainty or mismanagement can be mitigated through adopting flexible and co-managed strategies, in which institutional arrangements and ecological knowledge are dynamically evaluated and adapted accordingly (Olsson et al. 2004). But ultimately whether and to what extent management measures are implemented, strongly depends on the evaluation of the status of target resources and the respective ecosystem. Such an evaluation requires the use of a reference level or threshold to which performance indicators can be compared. Such performance indicators enable managers to act when thresholds are approached or exceeded (Hall and Mainprize 2004). In the WIO region information on the dynamics of marine resources and their fisheries is scarce (van der Elst et al. 2005; Samoilys et al. 2015), making the formation of adequate management plans difficult.

This situation is prevalent in Zanzibar (Tanzania), where marine fisheries resources form the livelihood basis for most inhabitants (Jiddawi and Ohman 2002; January and Ngowi 2010). Here, the fishery is along with tourism and clove farming among the top growth sectors (January and Ngowi 2010), yet it is still small-scale with 95% of the fishery conducted within the nearshore areas (Khatib and Jiddawi 2010). As the fishery of Zanzibar is open-access (Sobo 2004) with low fees for fishing licenses and no tax payment for artisanal fishers, anyone can participate. Hence the number of fishing boats has more than doubled between 2003 (4115) and 2010 (8639) (Khatib and Jiddawi 2010). The limited opportunities for alternative livelihoods (Torell et al. 2010) and the increase in population and tourist numbers (Lange 2015; NBS 2018) have likely contributed to the growing fishing effort. This increase together with the lack of control and the use of destructive gears and small mesh sizes are said to have led to overexploitation of resources. Respective statements about signs of overexploitation of the inshore fisheries of Zanzibar can be found throughout the literature (e.g., Francis and Bryceson 2001; Mkenda and Folmer 2001; Ngusaru et al. 2001; Payet et al. 2001; Jiddawi and Ohman 2002; Torell et al. 2007; Phelan and Stewart 2008; de la Torre-Castro and Lindström 2010; Colbert-Sangree 2012; Thyresson et al. 2013; Wallner-Hahn et al. 2016). A closer look, however, into this literature reveals that most of these statements are based on the perception of fishers or on official landing statistics that are 18 years old. Indeed, the lack of current updated information on fishing effort and the dynamics of species-specific catches makes it difficult to verify these concerns. The only continuous fisheries data reported are highly aggregated annual landing data, which show a steady increase in catches.

This paper aims to evaluate the exploitation level in Zanzibar and to identify the most vulnerable fishing grounds and target species. For this (1) a systematic literature review of studies and reports addressing the status of the fisheries of Zanzibar was conducted; (2) ecological survey data of fish and invertebrate community indicators were obtained from published studies to extract threshold reference points; and (3) official landings data was analyzed using the catch-based method (Froese and Kesner-Reyes 2002) to classify the fisheries of reported target groups into developing, fully exploited, overexploited and collapsed.

2. Methodology

2.1. Study area and literature review

Zanzibar is a semi-autonomous island state in the Western Indian Ocean belonging to the United Republic of Tanzania. Zanzibar consists of two major Islands: Pemba and Unguja (Figure 1), which lie 40–60 km off the mainland. The total territorial waters of Pemba and Unguja, where all small-scale fishing activities take place, is estimated at 4001 km^2, with an estimated number of 27,187 fishers using boats in 2010 (approx. 7 fisher km^{-2}, Khatib and Jiddawi 2010). The fishery is artisanal, with traps, seines nets, handlines, and spears being the most dominant gears (Jiddawi and Ohman 2002; Khatib and Jiddawi 2010). Zanzibar is divided into ten districts, with a total of 224 landing sites (Khatib and Jiddawi 2010).

To evaluate the status of the nearshore fisheries of Zanzibar, the existing literature was sourced and reviewed using the keywords “Zanzibar” in combination with either “fishing,” “fishery,” “overexploitation,” “overharvesting,” “overfishing,” or “resource extraction” in the Web of Science and Google Scholar. A total of 22 papers that assessed the impacts or the status of the fisheries of Zanzibar were found. The studies were divided into three groups: (1) Interviews with fishers; (2) Ecological surveys; (3) Fisheries statistics and assessments. The ecological indicator values obtained from the ecological surveys were used to extract warning thresholds (see section 2.2.). The official fisheries statistics were then analyzed to assess the state of the nearshore resources of Zanzibar (see section 2.3.). A visualization of the methodological steps involved in this analysis are presented in Figure 2.

2.2. Ecological surveys and threshold analysis

The findings of the ecological surveys that compared indicators such as biomass, abundance, species richness/diversity, and mean fish length in sites that were fished,

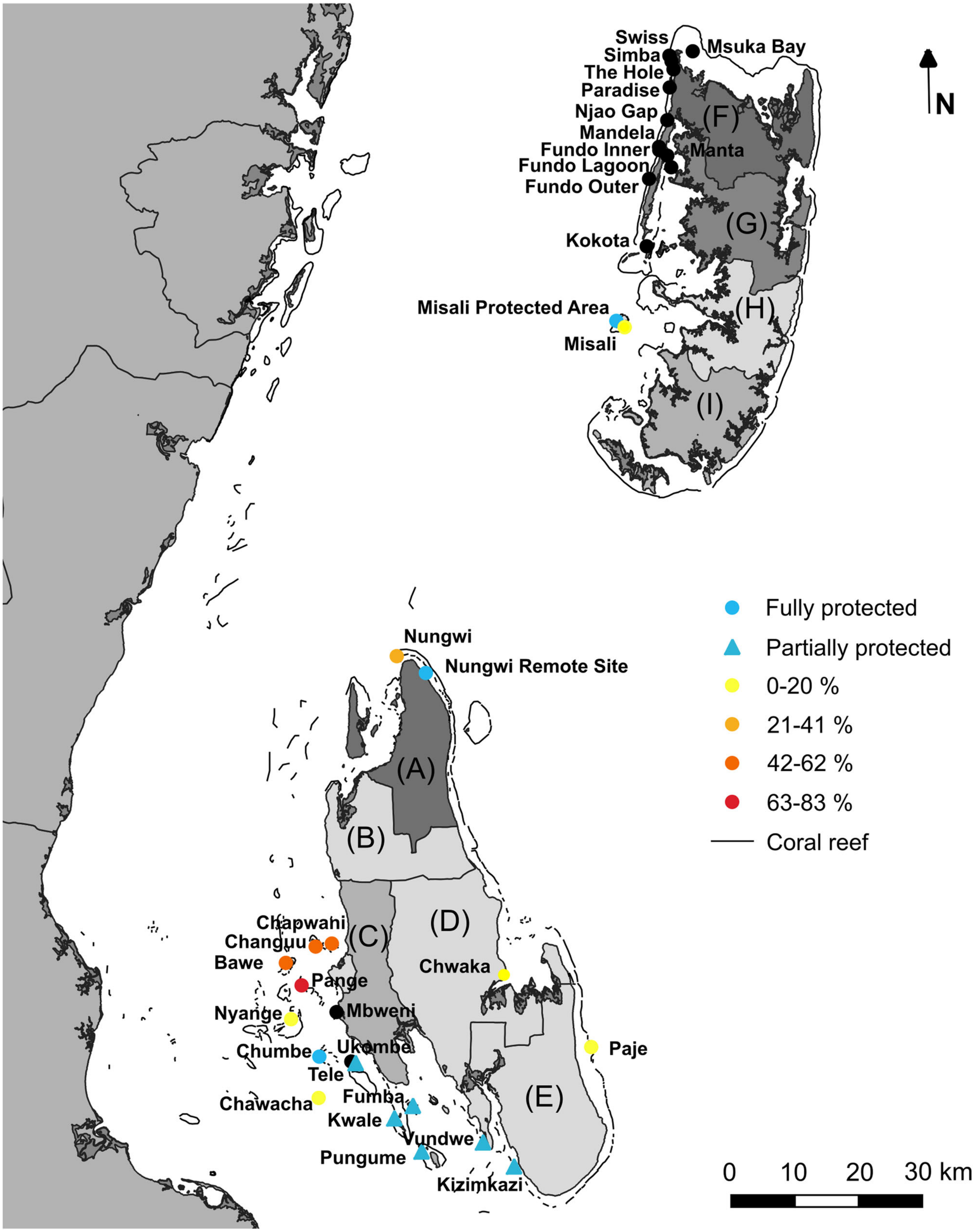

Figure 1. Map of Unguja and Pemba Island. Depicted are the different study sites of the ecological surveys. Colored circles represent the percentage of ecological indicators and taxa below the warning threshold calculated only for those studies, which reported the significance level of the observed differences. A–I represent the different districts colored according to the number of fishermen (increasing from light to dark gray): (A) North, (A, B) North, (B, C) West, (D) Central, (E) South, (F) Micheweni, (G) Wete, (H) Chakechake, and (I) Mkoani.

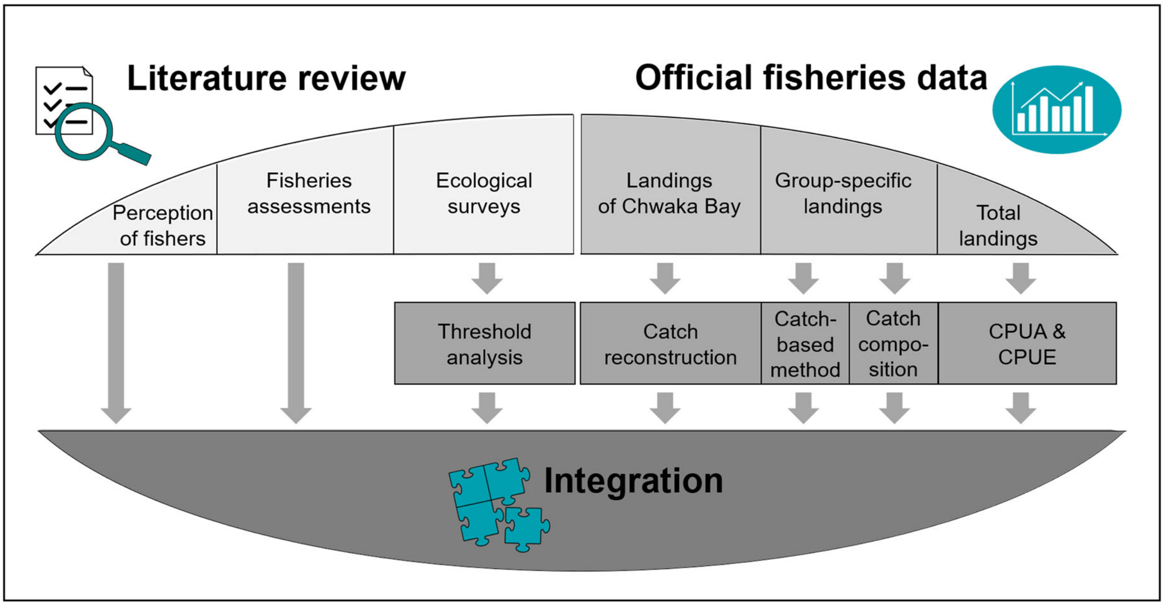

Figure 2. Flowchart of the methodological approach used: first, a literature review was conducted and official catch statistics were obtained from the DFMR and the FAO. Second, various analyses were applied to ecological surveys and catch statistics. Third, differences and similarities between the results were determined.

unfished (incl. remote sites) or partially protected (Figure 1) were reviewed. Table 1 lists the ecological surveys for which fishery indicators were obtained. For all studies, the fully/partially protected sites or the sites with zero fishing intensity were used as reference sites. Information on the effectiveness of protection was extracted directly from the publication (Table 1).

Warning thresholds of overexploitation for each of the ecological indicators were defined as follows: (1) a stock is reduced to half of the unexploited population size (B_{50}/N_{50}, Gulland and Boerema 1973); (2) the target species shows a 30% reduction in its mean length (L_{70}, Link 2005); and (3) species richness or diversity of an exploited community is reduced by 30% (SR_{70}/SD_{70}, threshold level was chosen analogous to L_{70}). Indicator values at fished sites were then compared with the warning thresholds calculated from the reference sites.

Changes below reference site thresholds were only considered to be a sign of overexploitation, when observed changes were reported by the authors as significant ($p = 0.05$). The study by McClanahan et al. (1999) compared indicators at multiple reef locations in East Africa and did not test for the difference between individual reefs. Therefore, the reported mean biomass values were used together with the standard deviation and the number of samples to test for significance with a two-tailed Welch t-test. The Welch t-test was chosen here because the authors stated that their samples were normally distributed. A more rigorous significance level was chosen ($p = 0.01$) because the original data was not available and thus the test was conducted on mean values and standard deviation only.

The changes in biomasses of excavators, grazers, and scrapers in the fully protected site Chumbe was also compared (no statistical test performed) between 1996 and 2009 using the data from McClanahan et al. (1999), Lokrantz et al. (2009), and data collected by the second author in 2009 (for the data see Supplementary material Table S2, and for details on the data collection see Samoilys, Halford et al. 2019). The data set from McClanahan et al. (1999) did not contain information on species level but only family. To compare functional groups instead of families (i.e., scrapers, grazers, and excavators), the 2009 data set was used to estimate the ratio of each functional group in the families Acanthuridae and Scaridae in the data set of McClanahan et al. (1999). The biomass ratio of grazing versus scraping Scaridae and grazing versus non-grazing Acanthuridae from the 2009 data set was used to estimate the biomass of scrapers and grazers from these two families in the 1996 data set (McClanahan et al. 1999).

2.3. Fisheries statistics and assessments

First, studies and reports that either provided information on fisheries statistics such as trends in catches (also called landings) or that conducted formal fisheries assessments were reviewed. As a second step, the official fisheries statistics of Zanzibar collected by the Department of Fisheries and Marine Resources (DFMR) were analyzed using Catch per Unit of Effort (CPUE), Catch per Unit Area (CPUA), species catch composition, and the catch-based method proposed by Froese and Kesner-Reyes (2002). The officially reported catch statistics were also contrasted with the reconstructed catches of Zanzibar provided by the Sea Around Us Project (Jacquet and Zeller 2007).

Table 1. Information of study sites, sampling period, sampling method, study organism, sampled indicators, and habitat variables of the ecological surveys for which fishery indicators were obtained and compared to the warning thresholds.

Study	Study sites	Reference site	Protection level of reference site	Study organism	Sampling period	Sampling method	Indicators used for comparison	Other indicators & habitat variables	Replicates
Fish surveys									
Alonso Aller et al. 2014	Changuu[a], Mbweni[a], Chumbe[a], Chwaka Bay[a]	Nungwi[a] Fumba[a]	Zero fishing intensity[b]	Algal herbivore fish, seagrass herbivore fish, invertebrate feeder fish, invertebrate and fish feeders, omnivore fish, juvenile fish, adult fish	Jan–Mar 2012	Belt transects	Abundance	Fish species richness/diversity, seagrass percentage cover and shoot biomass, seagrass epiphyte biomass, water depth, distance to corals and mangroves, wave exposure,	6
Daniels et al. 2003	Misali Island	Misali Island protected site	Not fully enforced, no-take marine reserve	Balistidae, Caesionidae, Carangidae, Acanthurinae, Nasinae, Scaridae, Siganidae, Haemulidae, Holocentridae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Epinephelini	2001	Box transects	Abundance length	Depth, substratum composition, hard coral cover, hard coral bleached, approximate substratum gradient	16
Grimsditch et al. 2009	Fundo Outer, Simba, Paradise, Swiss, Mandela, Kokota, Njao, Gap, The Hole, Manta, Fundo Inner, Fundo Lagoon, Msuka Bay	Misali Island protected site	Not fully enforced, no-take marine reserve	Total fish, herbivorous fish	Feb 2009	Belt transects	Abundance	Fish length, percentage cover of: Algae, hard and soft coral, seagrass, sand, rubble. Coral community structure, coral size class distribution, coral recruitment, crown-of-thorns starfish predation	3
Lokrantz et al. 2009	Changuu[c] Bawe[c] Pange[c] Nyange[c]	Chumbe Island Coral Park	Well enforced, no-take marine reserve	Excavators, scrapers, grazers	Nov–Dec 2004 & Oct–Nov 2006	Belt transects	Biomass, abundance length species richness species diversity	Sea urchin abundance, percentage cover of: live coral, coralline algae, macroalgae, turf algae, dead coral, soft coral, corallimorpharians, sediment, sand and other	10
McClanahan et al. 1999	Changuu Chapwani	Chumbe Island Coral Park	Well enforced, no-take marine reserve	Acanthuridae, Balistidae, Chaetodontidae, Labridae, Lutjanidae, Mullidae, Pomacanthidae, Pomacentridae, Scaridae, Siganidae	1996	Belt transects	Biomass species richness	Sea urchin density and biomass, predation rates on sea urchins, percentage cover of: hard coral, soft coral, algal turf, coralline algae, calcareous algae, fleshy algae, seagrass, sand and sponge	4–8
Tyler et al. 2011	Changuu Bawe Pange Chawacha Paje	Tele Kwale Pungume Vundwe Kizimkazi	Not fully enforced, partially protected marine reserve[c]	Detritivore, herbivore, invertivore, nekton/invertivore, nektonivore	Oct 2002–Mar 2003	Belt transects	Biomass, abundance length species richness	Sea urchin density, rugosity, percentage cover of: hard coral, soft coral, coralline algae, calcareous algae, turf algae, fleshy algae, rubble, rock, sand, seagrass, sponge, zooanthids	20–50

(*Continued*)

Table 1. Continued.

Study	Study sites	Reference site	Protection level of reference site	Study organism	Sampling period	Sampling method	Indicators used for comparison	Other indicators & habitat variables	Replicates
Invertebrate surveys									
Eriksson et al. 2010	Ukombe Kwale	Chumbe Island Coral Park	Well enforced, no-take marine reserve	Sea cucumber	Jun–Aug 2009	Manta tows	Species diversity	–	12
Fröcklin et al. 2014	Chwaka Bay 2010	Chwaka Bay 2005	–	Epibenthic macroinvertebrates	Mar–Jun 2005 & Jun–Aug 2010	Quadrats	Abundance	Percentage cover of: seagrass, algae, sand, rocks	232
Nordlund et al. 2010	Nungwi	Nungwi remote site	Inaccessible (approx. 10 km^2 by boat from coast)	Epibenthic macroinvertebrates	Oct–Dec 2007	Quadrats	Abundance biomass species richness	Biomass, shoot density and canopy height of seagrasses	20–22

[a]The authors assessed the level of fishing on the different sites using the number of houses within a 3 km^2 radius as a proxy for fishing effort assuming that fishers usually travel 3 km to their fishing grounds, which was based on reports from UNEP (2011) and Lokrantz et al. (2009). The sampling sites in Chumbe were located outside of the no-take zone in an extraction area.
[b]Nungwi and Fumba had zero fishing intensities, thus a mean value of both sites was used as reference.
[c]The authors based the fishing intensity on (1) number of days per week spent fishing per fisher, (2) the total number of fishing vessels or households at the different landing sites, and (3) distance of landing site to reef. The authors found a decreasing gradient of fishing intensity from north to south.
[d]Ban of illegal fishing methods including dynamite, dragnets, and poison.
[e]Authors only sampled in Chwaka Bay, therefore, values from 2005 were used as reference values.

The DFMR collects data on the landings (kg) of 19 target taxa: Siganidae, Scaridae,[1] Lethrinidae, Serranidae, Mullidae, Lutjanidae, Mugilidae, clupeioids (Clupeidae), sardines (*Sardinella spp.*), mackerels (Scombridae), Carangidae, tuna-like fishes (Scombridae), marlins & sailfishes (Istiophoridae), kingfish (*Scomberomorus spp.*), Sphyraenidae, sharks & rays (Elasmobranchs), mollusks (i.e., octopus & squid), lobsters (Palinura), and other demersal & pelagic fish. Data collection takes place monthly at 31 landing sites distributed across all districts, and information is stored in hard copies. These data are extrapolated by the DFMR to the whole of Zanzibar using information of relative fishing effort in the non-sampled landing sites obtained from irregularly conducted frame-surveys (Jiddawi and Khatib 2007; Khatib and Jiddawi 2010). The DFMR then reports annual landing data per target taxa to the FAO.

2.3.1. Catch composition, CPUE, and CPUA

The proportion of the different target groups to the total annual catch over time was plotted to detect changes in relative importance. Besides, the CPUE (where effort was per fisher per day) and CPUA were calculated using the total annual reported landings of Zanzibar, the territorial fishing area estimate of 4001 km^2, and the effort data reported by the frame surveys (Khatib and Jiddawi 2010), and extracted from Jacquet and Zeller (2007) and Hoekstra et al. (1990). Annual catches of Chwaka Bay, located on the east coast of Unguja (Figure 1), in 2011, 2012, and 2013 were reconstructed from catch data obtained in 2014 from the DFMR. The data represented monthly catches by target group and landing site (Chwaka village and Uroa village). Only 2012 catch data had all months at both landing sites; in 2011 and 2013 only the catch of six months was available. The information from 2012 was used to calculate the ratio between total annual catch and monthly catches. The subsequent ratio was then used to reconstruct the catch of the missing month for 2011 and 2013. Finally, the annual catches of Chwaka Bay were graphically compared from the reconstructed years with information from 1990 and 2004–2007 obtained from Jiddawi (2012).

2.3.2. Total catch analysis: Catch-based method

The catch-based method proposed by Froese and Kesner-Reyes (2002) classifies a fishery into developing, fully exploited, overexploited, and collapsed. For this purpose, the time series of catches is divided into two periods: before and after the year of historical maximum catch (C_{max}). In the period before C_{max} the catches are classified into developing ($<0.5\,C_{max}$) and fully exploited ($>0.5\,C_{max}$). In the period after C_{max} the catches are classified into fully exploited ($>0.5\,C_{max}$), overexploited

[1]Scarinae (parrotfishes) are in the Labridae family but have been reported as Scaridae in the past.

(0.1–0.5 C_{max}), or collapsed (<0.1 C_{max}). A loess smoothing was applied to the log-transformed raw data (Anderson et al. 2012) before classification because the catch-based method has been criticized for overly classifying fisheries as overexploited or collapsed due to stochasticity (Branch et al. 2011) (see example in Supplementary material Figure S1).

The catch-based method was applied to two DFMR data sets: (1) total landings for Zanzibar covering the period from 1990 to 2012; (2) landings for Unguja Island only, covering the period from 1990 to 2010 (see raw data in Supplementary material Tables S3 and S4). Two target taxa were removed from this analysis because they are so overly aggregated that the results will be meaningless in terms of assessment: sharks & rays and other demersal & pelagic fishes. The first data set was complemented with information for 2013 and 2014 from the official fisheries production statistics reported to the FAO. For mackerels and king fish, only the data from DFMR (until 2012) was used, because of inconsistencies found in the FAO data, possibly due to their method of pooling kingfish and mackerels into the seerfishes nei. The catch-based method was applied to the combined Zanzibar data set, and to Unguja alone between 1990 and 2010 to reduce the variance in the data because the fishery of Unguja is more developed than the fishery of Pemba (Khatib and Jiddawi 2010).

All analyses were performed in R version 3.4.4 (R Core Team 2018).

3. Results

3.1. Interviews with fishers

Nine studies were found spanning 2004 to 2016 that interviewed fishers about their perception of resource status, with only one study from Pemba Island. Semi-structured interviews conducted in 2002/2003, 2005/2010, and 2014 with fishers from Chwaka Bay (Figure 1) revealed a perception of a decrease in individual catches, particularly, those of Carangidae, Lutjanidae, Serranidae (de la Torre-Castro and Rönnbäck 2004; Geere 2014) and invertebrates (Fröcklin et al. 2014). Two of the central reasons given by the fishers for the decline was the use of dragnets and the increase in the number of fishers. Likewise, fishers from Kizimkazi Dimbani and Jambiani (Figure 1) reported a decrease in their average weekly catches over the last 20 years, which they mainly attributed to the continuous use of illegal fishing methods (spear-guns, noxious or poisonous substances, explosives, gears with mesh-sizes below legal size) (Colbert-Sangree and Suter 2015). A study that assessed the migration pattern of fishers from Pemba in 2011 found the reasons for migration were diverse and complex, but 60% of fishers mentioned that a decrease in the availability of fish within their fishing grounds led them to migrate to other places (Wanyonyi et al. 2016). Fishers also reported observations of decreasing catches for specific resources such as parrotfish (Thyresson et al. 2011), sardines (Stanek 2015), sea cucumbers (Eriksson et al. 2010), and invertebrates (Nordlund et al. 2010; Fröcklin et al. 2014). The frequently mentioned reason for those taxa-specific declines was again the increase in the number of fishers. The sea cucumber fishery on Unguja Island seems to be particularly impacted as not only fishers but also most middlemen said it was becoming more difficult to find the most valuable species (Eriksson et al. 2010).

3.2. Ecological surveys

Nine ecological surveys of fish and invertebrate communities were found, seven from Unguja and two from Pemba Island spanning 1999 to 2014. From the six fish community surveys, only one was conducted in seagrass meadows; the rest were carried out at reef sites. First, the findings of the authors for each study are summarized and then it is reported whether changes in ecological indicators were below or above warning thresholds (Supplementary material Table S1).

3.2.1. Ecological surveys of fish communities

McClanahan et al. (1999) and Lokrantz et al. (2009) surveyed two and four unprotected reefs on the West Coast of Unguja Island. McClanahan et al. (1999) found significantly lower fish density and for some target fish families significantly lower biomass and species richness. Likewise, Lokrantz et al. (2009) found that most indicators for herbivorous reef fish (abundance, richness, diversity, and biomass) were negatively correlated with reef-specific fishing pressure. The biomass of three and five out of ten families in Changuu and Chapwani in 1996, the biomass of all herbivorous fish in Changuu and Pange, and the biomass of excavators and scrapers in Bawe in 2004 were significantly reduced below B_{50} (Supplementary material Table S1). Species richness of Acanthuridae, Balistidae, and Scaridae in Changuu and Chapwani in 1996 and species richness of scrapers and grazers in Changuu, Pange, and Bawe in 2004 were significantly reduced below warning thresholds (Supplementary material Table S1). But species richness of excavators was not significantly different among reefs (Lokrantz et al. 2009, Supplementary material Table S1). Besides, the median size class of excavators was below L_{70} in Pange, Bawe, Changuu and the median size class of scrapers was below L_{70} in all fished sites in 2004 (Supplementary material Table S1). The authors, however, did not test for the significance of differences in size class distribution between sites.

Comparing the different ecological surveys conducted in the fully protected Chumbe area, revealed a declining trend in the biomasses of excavators and scrapers between 1996 and 2009. Grazer biomass, in contrast, increased between 1996 and 2004 and after that declined again (Figure 3).

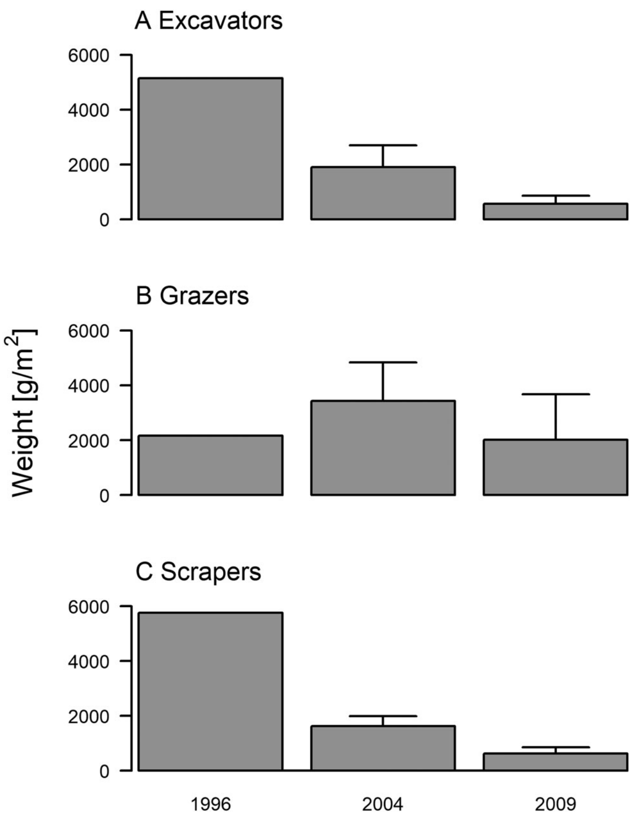

Figure 3. Changes in the biomass of excavators, scrapers, and grazers in Chumbe between 1996 (McClanahan et al. 1999), 2004 (Lokrantz et al. 2009), and 2009 (Samoilys).

Tyler et al. (2011) did not find any significant difference in the total abundance, biomass, or mean length of fish in the unprotected reef sites compared to the partially protected reef sites in Menai Bay. Furthermore, these authors did not find any significant difference in important habitat variables (e.g., hard coral cover) between protected and unprotected reefs. Overall species richness as well as species richness of detritivores, herbivores, and invertivores was significantly lower in the fished areas, exceeding warning thresholds (Supplementary material Table S1).

Alonso Aller et al. (2014) found the level of development (i.e., fishing intensity) to be negatively related to fish density, species richness, and species diversity. The densities of total fish and all functional groups, except omnivore fish, exceeded warning thresholds at Changuu and Mbweni, while at Chumbe fish densities of only algal herbivore fish and omnivore fish were below warning thresholds (Supplementary material Table S1). In Chwaka Bay none of the functional groups showed reductions in densities below warning thresholds.

Daniels et al. (2003) and Grimsditch et al. (2009) surveyed different reefs along the West Coast of Pemba in 2001 and 2009. While Grimsditch et al. (2009) found at all surveyed sites a lower fish abundance than in the protected Misali reef site (esp., browsers, scrapers, excavators, and non-herbivorous fish), Daniels et al. (2003) only found significantly lower abundance for Holocentridae. These were found to exceed warning thresholds (Supplementary material Table S1).

Alonso Aller et al. (2014) and Grimsditch et al. (2009) did not provide information on significance levels of observed differences in fish abundance between fished sites and reference sites.

3.2.2. Ecological surveys of invertebrate communities

Nordlund et al. (2010) found that epibenthic invertebrates had significantly higher species richness and abundance at the remote seagrass site compared to the exploited seagrass site in Nungwi. Only the reduction in abundance was found to exceed the warning threshold (Supplementary material Table S1). Similarly, Fröcklin et al. (2014) found that the total number of epibenthic invertebrates in Chwaka Bay was significantly lower in 2010 compared to 2005. This reduction did not exceed warning thresholds (Supplementary material Table S1).

None of the three analyzed invertebrate surveys reported statistical significance for changes in ecological indicators of individual groups. But the abundance of crustaceans, gastropods, and echinoderms in Nungwi as well as of bivalves, and gastropods in Chwaka Bay (2010) was reduced below warning thresholds. Furthermore, the overall lower species diversity of sea cucumbers in the unprotected reef compared to the protected reef (Eriksson et al. 2010) exceeded warning thresholds (Supplementary material Table S1).

3.3. Fisheries statistics and assessments

3.3.1. Trends in landings and fisheries assessments

The total annual landings of Zanzibar and several fishery specific landings showed declining trends between 1980 and 2000. Jiddawi and Ohman (2002) reported that the annual catch in Zanzibar declined from ca. 20,000 t in the 1980s to approximately 15,000 t in 2000 (Figure 4a). Similarly, the catches of small pelagics from boats of the Zanzibar Fisheries Corporation dropped from 600 t in 1986 to 91 t in 1997, and the landings of the reef fishery declined from approx. 3660 t yr^{-1} in 1990 to approx. 3450 t yr^{-1} in 1997 (Jiddawi and Ohman 2002). The total annual landings of Zanzibar between 1980 and 2014 and the reconstructed data from 1950 to 2005 provided by the Sea round us project (Jacquet and Zeller, 2007, Figure 4a) indicate an overall increase in landings from about 8313 t in 1950 to 31,267 t in 2014. After 1984 landings dropped to about 7842 t (reconstructed catch 9839 t) in 1991 but since then have increased steadily.

Information on area-specific catches was only found for Chwaka Bay (Figure 4b) and Menai Bay (Figure 4c,d). Jiddawi (2012) shows that the total annual catch of Chwaka bay has fallen from 950 t in 1990 to 376 t in 2004. The reconstructed catches from 2011 to 2013 indicate that since 2004, catches have remained relatively

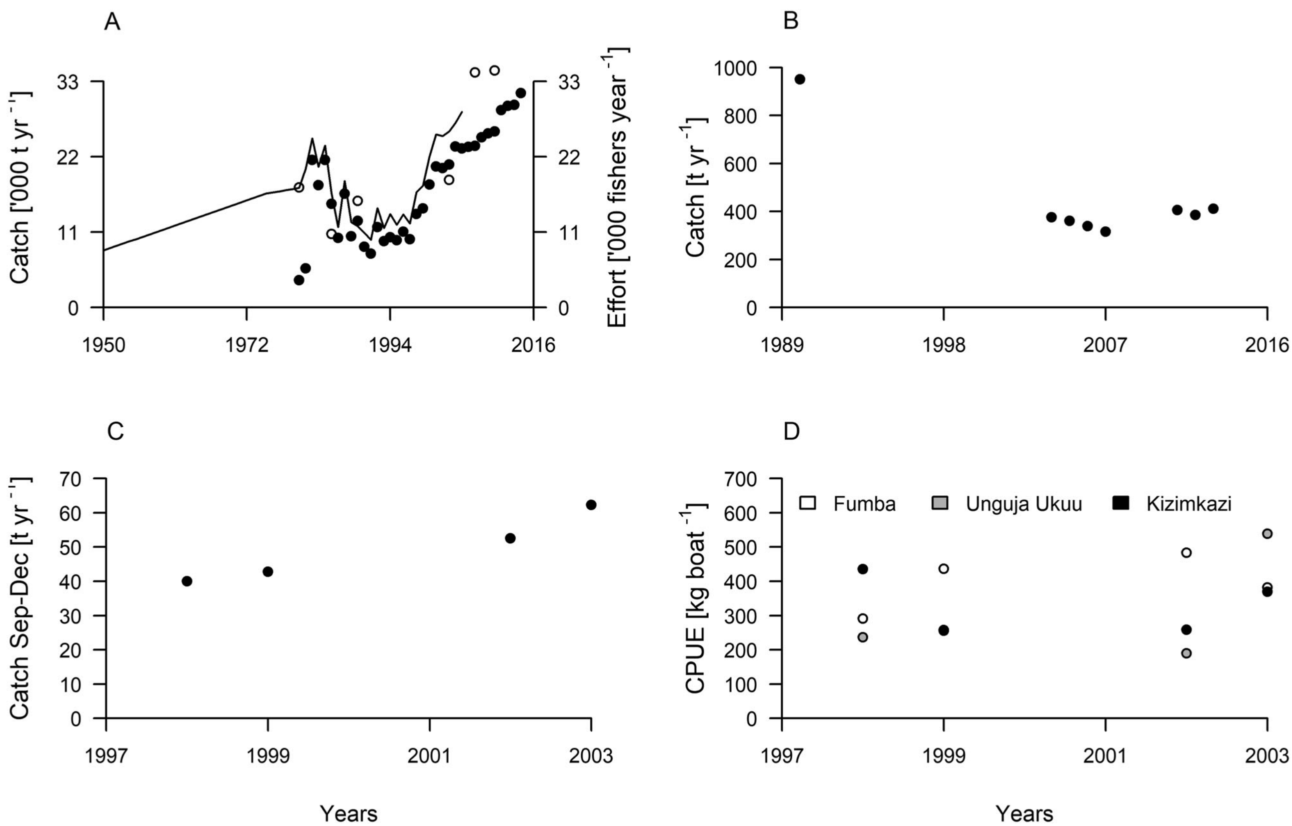

Figure 4. (A) Zanzibar total annual artisanal catch [t] between 1980 and 2014 (black points, DFMR; Ngusaru et al., 2001) and the corresponding annual effort [fishers] (white points) for 1980, 1985 (Jacquet and Zeller 2007), 1989 (Hoekstra et al. 1990), 2003, 2007, and 2010 (Khatib and Jiddawi 2010). Reconstructed catches from Jacquet and Zeller (2007) for 1950–2005 are represented by a straight line. (B) Total annual catch of Chwaka Bay [t] from 1990, 2004–2007 (Jiddawi 2012), and reconstructed total annual catch from 2011 to 2013 (DFMR). (C) Total catch of Fumba, Unguja Ukuu, and Kizimkazi and (D) standardized catch per unit of effort [kg boat^{-1}] in Sep–Dec between 1998 and 2003 (Davies and Jiddawi 2006).

stable (Figure 4b). Davies and Jiddawi (2006) collected catch data between 1998 and 2003 for three villages inside the Menai Bay marine protected area: Fumba, Unguja Ukuu, and Kizimkazi. While catches show a steady increase between 1998 and 2003 from 39 t to 62 t (Figure 4c), the standardized CPUE of the three villages was highly variable and did not reveal a clear down- or upward trend (Figure 4d).

Only three studies were found conducting quantitative fisheries assessments. Mkenda and Folmer (2001) used the official landing data from 1980 to 1996 to estimate the aggregated maximum sustainable yield (MSY) of the near-shore resources of Zanzibar. Analyses were based on Schaefer and Fox surplus production models using catch (t month^{-1}) and effort (fishing days fisher^{-1}month^{-1}) data of four different types of gears. Their MSY-estimate of 24,481 t y^{-1} was in line with rough estimations provided by the FAO. The annual yield between 1990 and 1996, however, was only about 40% of the calculated MSY, and the average annual effort exceeded with 657,762 units the calculated optimum (361,446 units), indicating biological overfishing.

Rehren et al. (2018a) conducted a comprehensive stock assessment on six of the main target species (i.e., *Siganus sutor* Valenciennes 1835, *Leptoscarus vaigiensis* Quoy and Gaimaird 1824, *Lethrinus borbonicus* Valenciennes 1830, *Lethrinus lentjan* Lacépède 1802, *Scarus ghobban* Forsskål 1775, and *Lutjanus fulviflamma* Forsskål 1775) of Chwaka Bay. This study used a length-based approach to estimate current exploitation rates together with biological reference points. Results show that all six species are harvested at a rate exceeding precautionary biological reference points ($E_{0.1}$).

Extending the assessment of the fishery of Chwaka bay one step further Rehren et al. (2018b) constructed an *Ecopath with Ecosim* model to evaluate the status of the ecosystem of the bay and to assess the impacts of the different gears in use. The authors compared the mean trophic level of the catch, the catch diversity and the mean length of the catch of the different fishing gears of Chwaka Bay to the Kenyan fishery (McClanahan et al. 2008; Samoilys et al. 2017), and concluded that the Chwaka Bay fishery seemed less depleted. When compared with other similar *Ecopath* models, however, the Chwaka Bay system showed relatively high transfer efficiencies and comparatively low fish biomasses, which point to a high exploitation pressure.

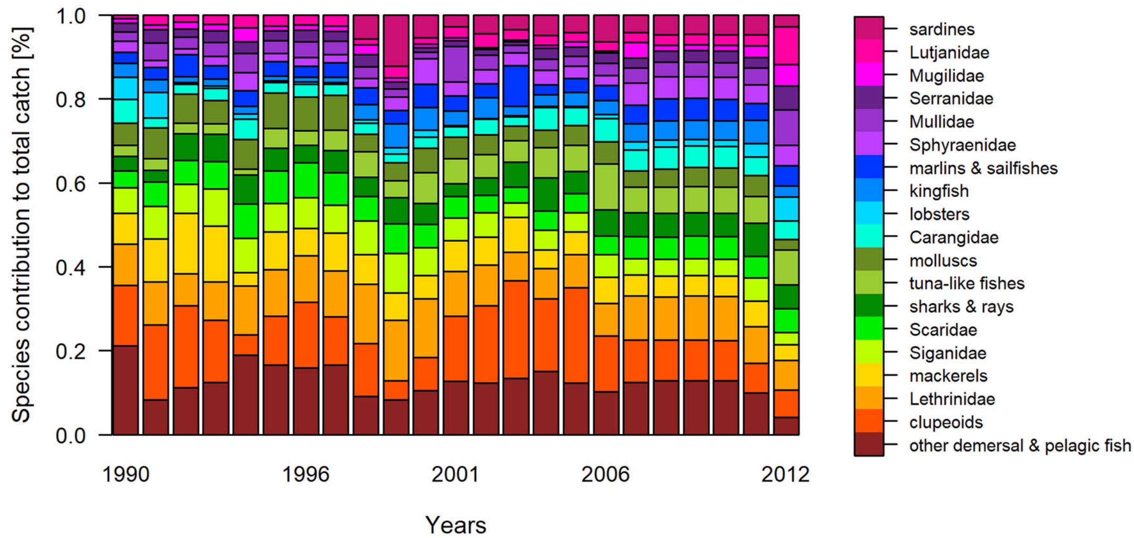

Figure 5. Percentage contribution of the 19 fisheries target groups to the annual total catch of Zanzibar between 1990 and 2012.

3.3.2. Catch per unit of effort, total yield, and catch composition

Information on overall fishing effort was only available for 2003, 2007, 2010. Using an average of 200 fishing trips per year per fisher and the officially reported annual landings, estimates of the average CPUE varied between 2003 and 2010 from 5.6 kg $fisher^{-1} day^{-1}$ in 2003 to 3.4 kg $fisher^{-1} day^{-1}$ in 2007, and then increased slightly to 3.7 kg $fisher^{-1} day^{-1}$ in 2010. Using the total fishing area of 4001 km^2, the catch per unit of area for Zanzibar amounted to 6.4 and 7.8 t km^{-2} in 2010 and 2014.

The relative contribution of the 19 target groups to the total annual catches from 1990 to 2014 shows a range of contributions between 1.5 and 13% (Figure 5). Before 2000, four to five families contributed to the first 50–55% of the total catch in most years, and after 2000 this number increased to about seven: Lethrinidae, clupeiods, mackerels, tuna-like fishes, sharks & rays, Siganidae, and Scaridae. While tuna-like fishes, sharks & rays and Sphyraenidae increasingly appear in the top bracket over time, mackerels, Siganidae, Scaridae and mollusks experience the reverse trend.

3.3.3. Analysis of the landings of Zanzibar—the catch-based method

The catch-based method was used to identify target groups that might be harvested at unsustainable levels. Figure 6 shows the results of a subset of the target groups of Unguja. Analysis of the remaining groups and all groups of Zanzibar can be found in Figures S2 and S3 (Supplementary material).

If the catch of a given group falls into the upper half of the graph, the stock is classified as fully exploited (i.e., catch >50% C_{max}), indicating that the current fishing intensity is exploiting these groups around their limits. If, on the other hand, catch levels after the year of the maximum catch, lie at the bottom of the graph, the stock is classified as overfished (i.e., catch >10–50% C_{max}) or collapsed (i.e., catch <10% C_{max}).

Results show that 12 of the target fishery groups (i.e., Scaridae, Lethrinidae, Serranidae, Mullidae, sardines, tuna-like fishes, mollusks, Figure 6; and Lutjanidae, Mugilidae, marlins & sailfishes, kingfish, Sphyraenidae Supplementary material Figure S2) out of the 17 analyzed target groups for the total landings of Unguja reached their maximum catch only in the last year of the time series (2010) and thus may be still developing. Four groups (i.e., Siganidae, mackerels, Carangidae, lobsters, Figure 6) were classified as fully exploited. Similar patterns were found for the total catches of Zanzibar, except for mollusks and Lethrinidae, which were classified as fully exploited (Supplementary material Figure S3).

The recent catch of Unguja in 2010 of clupeioids was classified as overexploited as catches fell below 50% of maximum catches (Figure 6). This trend remained when aggregating Unguja and Pemba catches (Supplementary material Figure S3). Lobster catches had their maximum in 1990 and were classified as overexploited for the first time in 1992 and shortly after (1998) catch levels collapsed (<0.1 C_{max}) but have recovered since 2008. When aggregating the lobster catch of Pemba and Unguja, however, the maximum catch was only reached in the last year of the time series, masking the declining trend of the lobster stocks of Unguja (Supplementary material Figure S3).

4. Discussion

4.1. From perception of fishers to official catch statistics

The perception of fishers and official catch statistics present a rather contrasting picture: while fishers perceive a decline in their catches, officially reported total catch of Zanzibar as well as group-specific catches show an overall increase.

The perception of fishers is often the first starting point to assess a decrease or increase in fisheries resources when no other information is available. Their perception, however, can be biased, limiting their power to perceive trends (Papworth et al. 2009; Daw 2010; Verweij et al. 2010; Daw et al. 2011). Furthermore, the

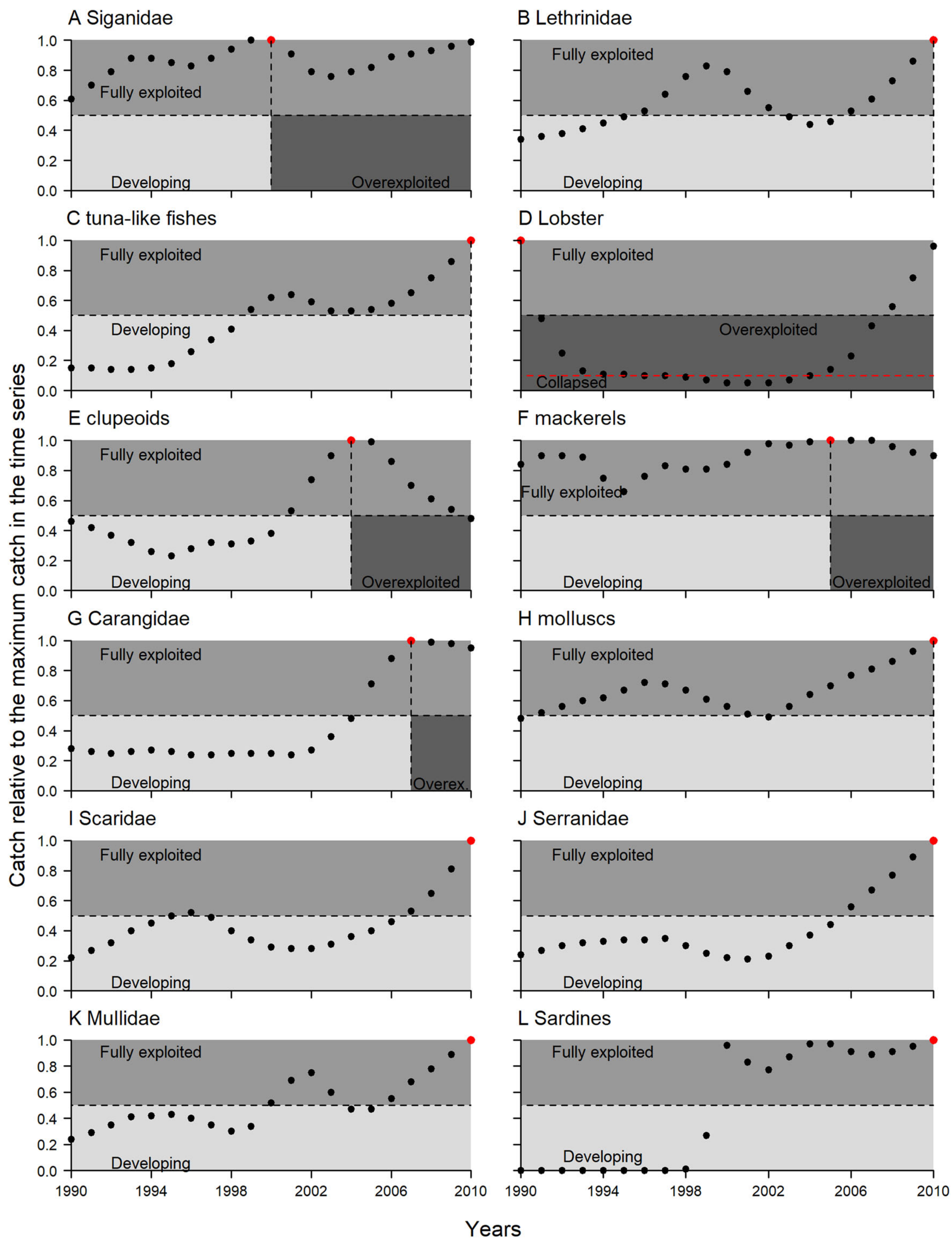

Figure 6. Annual catch of Unguja of a subset of target groups relative to their maximum catch (highlighted with red dots). The logarithm of the annual catch was smoothed with a LOESS function prior to classification. Catch levels that are developing (i.e., 0–50% C_{max}) can only occur before the maximum catch and are highlighted in light gray. Fully exploited catch levels (i.e., >50% C_{max}) are highlighted in medium gray. Catch levels after the maximum catch that fall below 10–50% of C_{max} are classified as overexploited and are highlighted in dark gray. The red dashed line in the lobster plot (d) mark the threshold of collapsed catches (i.e., catch < 10% C_{max}).

perception of fishers of declining resources is usually based on the decline of catch per fisher. In fisheries science theory, however, yield is maximized, when the abundance level of a stock approaches half the unexploited population size (B_{50}, Maunder et al. 2006). Consequently, fishers will commonly experience a decrease in their catch rates, when effort increases; but only if the stock size is reduced below B_{50} does biological overfishing occur (Maunder et al. 2006; Kolding et al. 2014). The findings of questionnaires, therefore, must be cross-validated with statistical analysis of catch and effort.

The annual fisheries landing statistics of Zanzibar prior to 2000, suggested a decrease of total landings, which is repeatedly referred to as an argument of overexploitation (e.g., de la Torre-Castro and Lindström 2010; Nordlund et al. 2010; Wallner-Hahn et al. 2016). The decline in landings between 1984 and 1991 was partly accompanied by a decrease in the number of fishers (Jacquet and Zeller 2007). Since the mid-90s catches from Zanzibar started to increase again alongside the fishing effort (Jacquet and Zeller 2007); and the total time series of annual landings (i.e., 1980–2014) show a steady increase since then. These trends contrast the more oscillating pattern of Kenyan catches (Tuda and Wolff 2015). Both fisheries are very similar in terms of catch composition, gear and boat use (Fulanda et al. 2011; Samoilys et al. 2011). Although the catch of Zanzibar is about three times that of Kenya with nearly twice as many fishers (Tuda and Wolff 2015), its CPUA estimate is lower (6.4–7.8, compared to 11–12 t km^{-2} in Kenya, Tuda and Wolff 2015). Furthermore, despite the higher fishing effort of Zanzibar, the catch per fisher per day (3.7–5.6 kg) is similar to slightly higher than CPUE estimates of the coral reef fisheries of Kenya from 1995 to 2006 (ranging from 2.7 to 4.9, Samoilys et al. 2017).

The mostly continuous increase of the landings of Zanzibar could stem from higher demands due to increasing population and tourist number (Lange 2015; NBS 2018), improved technologies and improved fisheries management (Bultel et al. 2015), but they could also be due to a geographical expansion of the fishery, an enhanced data collection and increased reporting of catches. The latter factors might be more relevant: it has been shown that fisheries production statistics from the Indian Ocean and Western Central Pacific Ocean are the only areas that are still reporting an increase in catches, which has been attributed to increased reporting of national small-scale fisheries catches (Pauly and Zeller 2016).

It is also important to note that total annual landings obscure the dynamics of individual stocks. Seemingly healthy stable landings can mask changes in species composition and decreases in the mean trophic level of catches, as shown in the case of the Kenyan fishery (Tuda and Wolff 2015; Samoilys et al. 2017). An evaluation of taxa-specific landings for Zanzibar and Unguja Island between 1990 and 2010/2014, nevertheless, show a similar trend with several group-specific landings still increasing in the last year of the time series; and no dramatic shift in species composition toward domination by herbivore families. Indeed, the opposite was observed, with Siganidae and Scaridae becoming less important in the catches after 2000, while the mesopredators Serranidae and Lethrinidae are increasingly or consistently dominant, and pelagic predators such as tuna-like fishes and Carangidae gain in importance. The increase in the number of dominating target groups in the catches of Zanzibar could also suggest a loss of dominance of economically more valuable species. Particularly, the reduction in the contribution of Scaridae might reflect a loss of abundance considering that fishers throughout Unguja perceived a decrease in catches and this group showed significant reductions below warning thresholds at the West Coast. The only fish target group that has been classified as overfished are clupeioids, which needs to be interpreted with caution because small pelagic fish are characterized by high decadal variability in biomass (Checkley et al. 2009).

The catch-based method provided by Froese and Kesner-Reyes (2002) and other catch only methods have been identified as poor classifiers of stock status (Free et al. 2020). The method has been criticized for overly classifying fisheries as overexploited or collapsed due to stochasticity (Branch et al. 2011). The here used smoothing is just one attempt to overcome this limitation (Anderson et al. 2012). While the results of the catch-based method on the raw and smoothed data for Zanzibar are very similar, the data from Unguja yields a different picture: Lutjanidae, Mullidae, and Mugilidae are classified as overfished when analyzing the raw data. This is due to sudden, high catches in individual years, which drive the classification (see Supplementary material S.1.). A more important limitation of this and other data-poor methods for assessment, is that they require a comprehensive time series of catches (Zeller and Pauly 2018). The catch information from Zanzibar at the taxa group level is only available since 1990, while coastal fisheries have been exploited for a long time to provide food and income to local communities. Thus, some groups may have had already reached their maximum catches before 1990. In the Kenyan fishery, for example, the sharp increase in landings between 1950 and 1970 was followed by a substantial decline (Tuda and Wolff 2015).

In the absence of appropriate time series and adequate taxonomic and spatial resolution of catch data, assessing the general state of the nearshore fisheries of Zanzibar remains difficult. But even if catch and effort trends do not suggest a sign of biological overfishing, perceived catch declines by fishers should raise concern for food security and the sustainability of fishing as a livelihood.

4.2. Spatial disaggregation of fishing effects

The review of the ecological fish surveys suggests that a clear decline below warning thresholds of fish community indicators has been demonstrated for the reefs on the west coast of Unguja Island (i.e., Changuu, Bawe, Pange & Chapwani), which is an important fishing area (Khatib and Jiddawi 2010). The biomass of Lutjanidae and Mullidae have been pushed below warning thresholds at these reefs, despite their continuous increase in the overall annual landings. Furthermore, the biomass of excavators and scrapers declined between 1996 and 2009 in the fully protected but relatively small (30 hectares) Chumbe Island Coral Park, which could be an indirect effect of heavy fishing in the adjacent areas. This is alarming as the loss of herbivore fish can enhance the proliferation of macroalgae and thus reduce the recruitment and survival of corals (Hughes et al. 2007).

Chwaka Bay (east coast) has been identified as a fully exploited fishing ground with some species being overexploited; for instance, the two commercially important Lethrinidae species *Lethrinus lentjan* and *Lethrinus borbonicus* (Rehren et al. 2018a, 2018b). These results are partly reflected in the total annual landings of Chwaka Bay, which experienced a steep decline between 1990 and 2004 but seemed to have stabilized since then. This further illustrates that the spatially aggregated trends in landings do not represent what is occurring at heavily exploited fishing grounds.

Menai Bay (south-west coast, Unguja) does not show clear indications of overfishing, when considering the fisheries statistics from 1998 to 2003 (Davies and Jiddawi 2006) and the ecological survey carried out from October 2002 to March 2003 (Tyler et al. 2011). The absence of significant differences in fish biomass/abundance, and live hard coral cover between partially protected and fished sites questions the usefulness of gear-based management interventions in Zanzibar. Tyler et al. (2011) reported that "Although enforcement has not been perfect, a large amount of anecdotal evidence suggests that there has been a reduction in the use of illegal fishing methods and the numbers of visiting fishermen, who were said to be the main users of these methods." Tyler et al. (2011), however, did not quantify gear-specific fishing effort, and it is therefore not clear (1) to what extent the enforcement of illegal fishing gears has been successful in the partially protected sites and; (2) whether an increased fishing effort of legal gears inside the protected area ruled out any positive effect on ecological indicators. Similarly, Samoilys et al. (2017) found no differences in fish densities of four families between managed government gazetted reserves (partially protected: allowing only traditional gears to operate) and fished sites in Kenya, but significant differences among government gazetted marine parks (no take zones) and marine reserves/fished sites. Further studies are needed to investigate the effect of removing illegal fishing methods on the fisheries resources of Zanzibar.

Since most surveyed sites were located on the west coast of Unguja Island, it remains unknown to what extent other areas are similarly impacted. The findings by Grimsditch et al. (2009) indicate that the west coast of Pemba is experiencing likewise heavy fishing pressure. Although the authors did not report on the statistical significance of their findings and their sample size was low, the frame survey of Zanzibar shows that fishing effort on the west coast of Pemba (i.e., Micheweni) is higher than on the west coast of Unguja (Khatib and Jiddawi 2010). This might support the conclusions of Grimsditch et al. (2009) that the west coast reefs of Pemba experience overexploitation.

4.3. Invertebrate harvesting

The invertebrate surveys showed intense exploitation of epibenthic macroinvertebrates on Unguja Island, with their abundance exceeding warning thresholds in Nungwi. The decrease in the lobster catches of invertebrate harvesters of Chwaka Bay (Fröcklin et al. 2014) is supported by the collapse of the lobster catches of Unguja in 1998 and the overall decline in export (Jiddawi and Ohman 2002). Future catches need to be carefully monitored as they have currently (2014) bounced back to high levels similar to those from 1990.

The lack of landings data of invertebrates other than lobsters and octopus & squids probably stems from the fact that fisheries data collection is mostly dedicated to vessel-based catches, missing the catches from gleaning activities. Particularly alarming is the lack of data for sea cucumber landings (Eriksson et al. 2010). This invertebrate group seems to be under intense pressure, as indicated by the reduction in species diversity, and further findings by Eriksson et al. (2010) that sea cucumber catches at Mkokotoni, Fumba, and Uroa consist of many low-value species and immature individuals. Although in a later study Eriksson et al. (2015) report that local fishing authorities classified the sea cucumber fishery as fully-exploited, the observation by fisher and middlemen from 2010, that it was harder to find most species today, is pointing to an overfished state. While fishers only report on their individual catches, middlemen should have a better overview of the total quantity of caught fish. This alarming situation on Zanzibar is no exception: 69% of 31 sea cucumber fisheries globally are classified as overexploited (Anderson et al. 2011b). The loss in sea cucumber is concerning as they play a major role in nutrient cycling which is especially important in coral reef environments (Purcell et al. 2016). Furthermore, they increase seawater alkalinity through excretion and feeding, which ultimately buffers ocean acidification (Purcell et al. 2016).

Invertebrates serve as a vital source for food security of local households (Fröcklin et al. 2014), with gleaning activities often being dominated by women (Samoilys, Osuka et al. 2019). Furthermore, they comprise the largest proportion of marine export products of Zanzibar (Jiddawi and Ohman 2002), and play a critical role in the functioning of ecosystems (Nakamura and Kerciku 2000; Anderson et al. 2011a). It is, therefore, recommended to (1) conduct annual household interviews in fishing communities to identify overall effort, and (2) collect information on monthly catches of a subsample of collectors to estimate annual invertebrate catches.

4.4. Future research

Ecological surveys can be cost-intensive and spatially limited, but they are a crucial fishery-independent approach to evaluate the impacts of fishing on target species and their habitats, particularly in the context of multispecies fisheries. Because fishing is likely to change the biomass of target species and the ecosystem structure, it is valuable to compare ecological indicators with reference points to fully assess if changes are a sign of overfishing. The here used warning thresholds and their values are just one attempt at such a comparison. Ideally levels for warning thresholds should be based on the knowledge of target species and ecosystem in question. Particularly, the threshold used for biomass reductions might be to high and could be set to more precautionary levels. Changes in indicators need to be related to manageable fishery input measures such as mesh size, total fishing effort and gear-specific fishing effort to set adequate management plans.

None of the ecological surveys directly quantified fishing effort, although detailed information is often collected by fisheries departments (catch, price, target family, gear, fishers, boat, and day) throughout the Western Indian Ocean but unfortunately only becomes available in a highly aggregated form (UNEP-Nairobi Convention and WIOMSA 2015). Limited personnel and technical capacities are likely responsible for this situation (UNEP-Nairobi Convention and WIOMSA 2015). Well-designed academic research studies involving fisheries department scientists and external collaborators are urgently needed, together with the streamlining of electronic recording of monthly catch and effort data collection. Several ecological surveys have been conducted on the west coast of Unguja Island, providing not only spatial, but also temporal information on the status of fish communities, and should be ideally used as baseline data for further assessments. This study provides additional information on the biomass of fish species of the fully protected Chumbe Island Coral Park (Supplementary material Table S2).

Future research projects that assess the status of the resources of Zanzibar should build on existing information, relate outcomes to fisheries input measures to be useful for managers, and integrate ecological surveys and fisheries assessments. Studies on the perception of fishers should be complemented with interviews of middlemen and other actors higher up the value chain to report on the status of overall and not individual catches. Such approaches then should be complemented with an

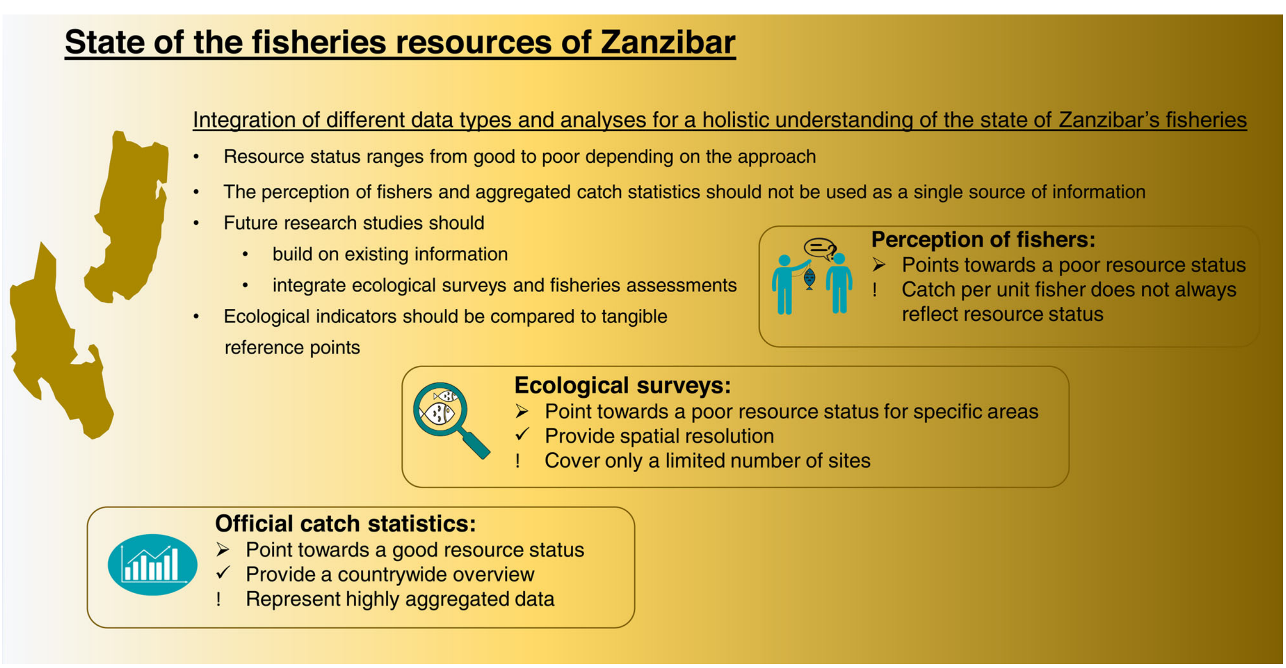

Figure 7. Summary of the findings from interviews with fishers, ecological surveys, and fisheries catch assessments on the status of Zanzibar's fisheries resources.

evaluation of market pressure overtime to identify socioeconomic drivers of fisheries catches (Crona et al. 2010; Brewer et al. 2012).

5. Conclusion

This study integrates information on annual fisheries statistics, the perception of fishers, and the findings of ecological surveys to assess the exploitation level of the nearshore fisheries of Zanzibar. Results indicate that while fishers can be overly pessimistic about the status of their resources (Figure 7), highly aggregated official landing statistics can paint an overly optimistic picture (Figure 7). The ecological surveys point to a midway between the two (Figure 7), with overexploited reef fishes on the west coast of Unguja Island. While ecological surveys often provide a much better spatial and taxonomic resolution, they are geographically limited, and their evaluation results cannot be raised to the country level.

In small-scale fisheries, information is often scarce and scattered, which makes it highly challenging to assess their status. The here used approach highlights that integrating information from local knowledge to fisheries-dependent and -independent data aids in a more holistic evaluation of their status. It is particularly useful in identifying areas and taxonomic groups of higher concern and guiding future research efforts toward contributing better information for fisheries management.

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