Ocean and Coastal Management 212 (2021) 105808

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

The complex relationship between asset wealth, adaptation, and diversification in tropical fisheries

Sarah F.W. Taylor[a,*], Shankar Aswani[b], Narriman Jiddawi[c], Jack Coupland[b], Phillip A. S. James[d], Stephen Kelly[a], Hellen Kizenga[e], Michael Roberts[a,f], Ekaterina Popova[a]

[a] National Oceanography Centre, Southampton, SO14 3ZH, United Kingdom
[b] Rhodes University, Grahamstown, South Africa
[c] Tanzania Fisheries Research Institute, Dar Es Salaam, Tanzania
[d] Independent, United Kingdom
[e] Institute of Marine Sciences, Zanzibar, Tanzania
[f] Nelson Mandela University, Port Elizabeth, South Africa

ARTICLE INFO

Keywords:
Small-scale fisheries
Asset wealth
Adaptation
diversification
Fishing portfolio
Food security

ABSTRACT

Marine small-scale fisheries are complex social and ecological systems that are currently pressurised by climate change, increasing demand for food, and expectation to sustain livelihoods. Species diversification and occupational diversification are often offered as adaptation strategies to increase the resilience of these fisheries to natural and economic shocks. However, little is known about the nature of species diversification within marine tropical fisheries. Based on 293 interviews with artisanal fishers from six coastal communities located at the isles of Zanzibar, Pemba, Mafia, and Mainland Tanga in Tanzania - we assess if fishers with the highest level of species diversification are the most financially secure and able to adapt to changes in the fishing industry. By creating an Asset Wealth Index (AWI) based on a Multiple Correspondence Approach (MCA), we investigate the relative levels of adaptive capacity and fishery connectivity within the different regional wealth quartiles. We find that less wealthy fishers target fewer species, making them less able to absorb changes in management measures focused on species, area, and closures. Likewise, fishers with higher wealth scores and higher adaptive capacity are able to better absorb the short-term losses of fisheries closures when compared to those with lower wealth and adaptive scores reliant on higher levels of fishery connectivity.

1. Introduction

Fish provided more than 3.3 billion people with 20% of their average per capita intake of animal proteins in 2017 (FAO, 2020). In developing countries, apparent fish consumption has increased significantly from 5.2 kg per capita in 1961 to 19.4 kg per capita in 2017 (FAO, 2020). Policy-making processes pertinent to food security in Africa are largely centred around cereals, pulses, and meats. The pivotal role that fish can play in food security is not adequately recognised, even within countries where fish is central to the population's diet (Kurien and López Ríos, 2013; FAO, 2020). Fisheries are, however, volatile and complex coupled social and ecological systems that are impacted by oceanographic changes, biological responses, and socio-economic conditions and linkages (Cline et al., 2017). In the context of new climate realities and globalised economies, there is a need to better understand the factors that enable access, resilience, and adaptive capacity within these volatile social and ecological systems (Osterblom et al., 2016).

The Tanzanian marine coastal fishery plays an important role as a source of protein-rich food and employment (Francis and Bryceson, 2001; Sekadende et al., 2020) with small-scale artisanal fisheries (SSF) representing the majority (95%) of total catch (Jiddawi and Öhman, 2002). Undernutrition is particularly high among low income Tanzanian households, mainly because they consume carbohydrate-rich staple-based diets low in minerals and vitamins (Leach and Kilama, 2009). However, in Tanzanian coastal communities, SSF play an important role in nutrition by adding variety and nutrient dense food to diets as the majority of fishers consume a portion of their catch (Taylor et al., 2019).

There is substantial risk involved in depending on fisheries for nutrition and livelihoods as SSF are exposed to natural and economic shocks and disasters (Allison et al., 2006). Livelihood diversification is

* Corresponding author. National Oceanography Centre, European Way, Southampton, SO14 3ZH, UK.
E-mail address: sarah.taylor@noc.ac.uk (S.F.W. Taylor).

https://doi.org/10.1016/j.ocecoaman.2021.105808
Received 28 November 2020; Received in revised form 7 June 2021; Accepted 30 June 2021
Available online 14 July 2021
0964-5691/

often a strategy used by fishers to respond to environmental, regulatory, and economic variability (Allison and Ellis, 2001; Salmi, 2005; Cinner and Bodin, 2010; Folke et al., 2010). A recent study conducted in Tanzanian coastal communities by Silas et al. (2020) found that the majority of fishers' household members (75%) were already involved in alternative economic activities outside of fisheries. Such diversification is imperative for households involved in SSF, for reasons such as to minimise income risk and increase adaptive capacity (Allison and Ellis, 2001; Berkes et al., 2001; Fuller et al., 2017). Adaptive capacity refers to the conditions that enable people to anticipate and respond to change, minimise the consequences, enable recovery, and take advantage of new opportunities (Grothmann and Patt, 2005).

Diversification can also apply within fisheries by targeting multiple species, different gear usage, and various fishing grounds. Fishery diversification is often proposed as a framework and adaptation strategy to increase the resilience of fisheries to fluctuations in fishery resources (Bell et al., 2018; MacNeil et al., 2010). This creates interlinked networks of alternative sources of income and acts to connect fisheries (Fuller et al., 2017). The cross-scale nature of fisheries connectivity, as Fuller et al. (2017) described it, is also important to consider when assessing the socio-economic resilience of coastal communities. The effects of fishery diversification are understood in the context of regulated fisheries within the United States of America (Anderson et al., 2017; Kasperski and Holland, 2013; Young et al., 2019; Sethi et al., 2014). However, less is known about the impact of diversification on fishing revenue in tropical fisheries. A recent study by Robinson et al. (2020) tested how catch diversification affects the catch success of individual fishers participating in declining tropical fisheries in Seychelles. They found that fishing vessels targeting multiple species in one fishing trip using several gear strategies had greater success in terms of larger catches and higher revenue compared to those who specialised on fewer groups. The results in Seychelles were congruent with the findings in the United States showing higher levels of species diversification can substantially reduce the variability of fishing income.

This study focuses on how fishers within different wealth quartiles perceive their ability to diversify livelihoods and how diverse their fishing strategies are. We utilise data from a survey conducted in four coastal regions in Tanzania (Tanga, Pemba, Zanzibar, and Mafia; Fig. 1). We question if wealthier fishers have greater ability to diversify livelihoods? Further, do wealthier fishers have highly diverse fishing portfolios? The study therefore applies the hypothesis (Fig. 2) based on aforementioned studies (Fuller et al., 2017; Robinson et al., 2020) to SSF in Tanzania to observe whether wealthier fishers are utilising diversification strategies to increase resilience and decrease financial risk associated to dependency on tropical marine fisheries.

We assess the research questions using a three-part approach. We begin by (1) producing an Asset Wealth Index (AWI), using a Multiple Correspondence Analysis (MCA) approach. This is done for two reasons. Firstly, it is a more inclusive indicator of wealth and gives a broader view of living standards compared to reported income. Secondly, this approach allows for fishing gear ownership to be included in the wealth analysis, which is an important enabler or barrier to levels of fishing income in Tanzanian coastal communities. We then (2) assess the ability of fishers to diversify their livelihoods by calculating an adaptive capacity score based on responses from survey questions around occupational flexibility. Lastly, we (3) assess how diverse or specialised fishing portfolios are by calculating a cross-fishery connectivity score based on survey questions around species targeted for both commercial and subsistence purposes.

2. Regional context

Before we proceed, it is important to frame our research questions within the geographical and socio-economic coastal regions of this study (Fig. 1). Tanzanian mainland and island coastal regions have different constraints and opportunities in terms of food and resource access, risk,

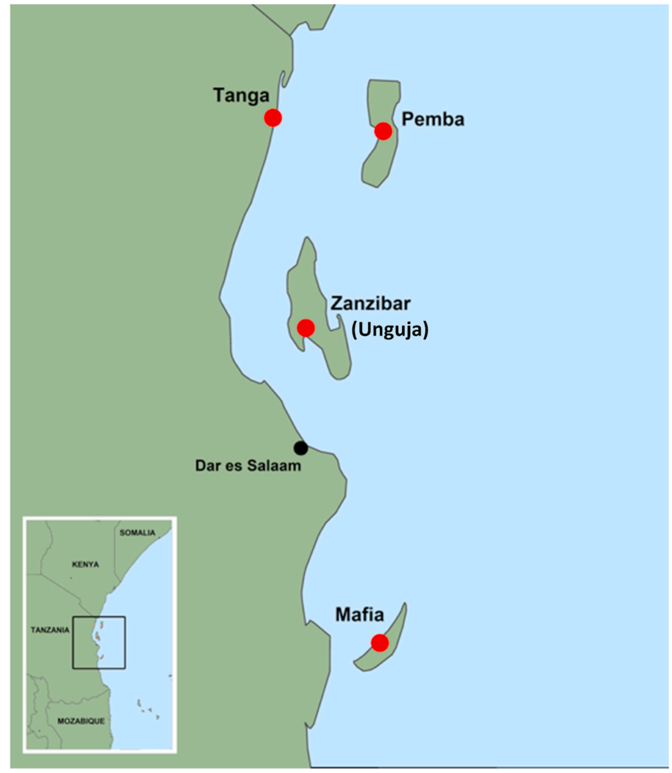

Fig. 1. Map of four regions used for interview data collection: Tanga, Pemba, Zanzibar, and Mafia.

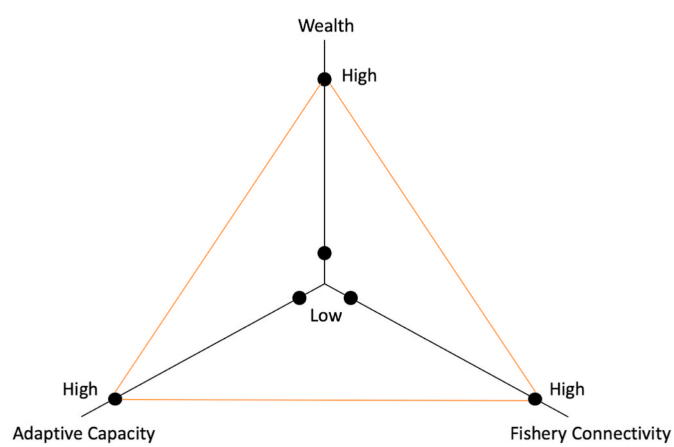

Fig. 2. A graphic representation of the hypothesis. Based on asset wealth quartiles, how connected are fishers to different species and what are the levels of adaptive capacity?.

resilience, and adaptive capacity. Fishers' ability to manage risk associated with volatility and adapt to change is largely a function of individual circumstances, including their *access* to different fisheries (Stoll et al., 2017). Species diversification requires access to multiple gear types and larger vessels that facilitate access to various habitats in both shallow and deeper waters. SSFs in Tanzania contribute to 95% of the marine fishery sector, while often being geographically limited to shallow coastal areas (Ngusaru et al., 2001; Semba et al., 2016). This is due to artisanal fishers using traditional vessels propelled by sail, paddles, and long poles (Jiddawi and Öhman, 2002). Only a limited number of fishers are able to target the large pelagic fish in deeper waters by using small motorised vessels (Jiddawi and Öhman, 2002; Kizenga, 2020). Another aspect to consider within gear ownership is that of economic gains received from catch differ substantially if the fisher does not own the vessel and/or gear. Boat or equipment owners (such as seine, ring, or gill nets) partner with fishers to enable their access to marine resources (Jiddawi and Öhman, 2002). However, the money earned from selling catch is then split into three. One part goes to the vessel owner, one is kept for maintenance of the boat and gear, and one part is split between all of the fishers that were part of the vessel crew (Jiddawi and Öhman, 2002).

The majority of fishers turn to agriculture during the rainy season in Tanzania as the poor fishing conditions necessitates diversification of livelihoods (van Hoof and Kraan, 2017). The monsoon winds also have some influence on fish landings in Tanzania. Strong South East Monsoon (SEM) winds create dangerous sea conditions which reduce the access to fishing grounds for SSF vessels (Jiddawi and Öhman, 2002). Winds are less strong during the North East Monsoon (NEM) allowing the sea to be relatively calm and fishing grounds to be more accessible for artisanal fishers (Breuil and Bodiguel, 2015).

Tanga is situated in mainland northern Tanzania and is surrounded by coral reefs, seagrass beds, mangroves, as well as deep channels and drop offs (Horrill et al., 2000). Tanzania's mainland coast has some of the most damaged coral reefs in the region, with Tanga being the most affected by dynamite fishing (Samoilys and Kavange, 2008). Fishers in this region are often not able to take advantage of productive fishing grounds offshore due to inefficient fishing vessels (Mwaipopo and Mahongo, 2020). Around 90% of men in Tanga coastal communities are engaged entirely in fishing and fish-related business (Mwaipopo and Mahongo, 2020). While women engage in fish mongering, off-loading from the boats, and processing fish. Alternative livelihood options for coastal communities include small business and small-scale farming (Samoilys and Kavange, 2008; Harrison, 2010; Mwaipopo and Mahongo, 2020). The main limitations to alternative livelihood development in these areas are access to markets, capital, health, and a lack of modern equipment (Harrison, 2010).

There are many reefs around the islands of Zanzibar and Pemba, which drop off sharply into vertiginous crevasses up to 40 m deep (Feidi, 2005). The marine capture fishery is carried out by artisanal fishers within the 12-mile territorial waters around the islands. However, most of the fishing takes place within 5 miles of the shore due to the small size of the fishing vessels. The fish stocks around these islands includes small pelagics, coral reef fish, lobsters, squid, octopus, and large pelagics. Reef fish and large pelagics appear to be more abundant around Pemba, while small pelagics are more abundant around Zanzibar (Feidi, 2005). Alongside fisheries, tourism and clove farming are among the top growth sectors in Zanzibar and Pemba as alternative livelihood sources (January and Ngowi, 2010).

Fishers in Mafia have restricted access to the eastern (offshore) side of the island, which is under more oceanic influence (Obura, 2004). The eastern side has an exceptionally steep continental slope with the fast East African Coastal Current (EACC) close to the shoreline. In contrast, the flats between the island and mainland are shallow and sheltered. Around 85% of people rely on fishing in Mafia with limited alternative livelihood activities, as poor soil and low capital investments disable agricultural development and the isolated geographical location of the island restricts the development of business-orientated enterprises (Kulindwa and Lokina, 2013; Rubens and Kazimoto, 2003).

3. Methods

3.1. Socio-economic survey

The Tanzanian research was conducted during two field campaigns - one in July 2018, the other in July/August 2019. The research team consisted of postgraduate students from Rhodes University (South Africa), as well as a team of translators organised by the Institute of Marine Science (IMS), Zanzibar in 2018 and by the University of Dar es Salaam in 2019. The field team was given training in the relevant survey techniques, and assisted with translations and cultural integration. Prior to the interviews, meetings were held with local authorities aiming to introduce the study and appeal for local cooperation. All interviews were conducted in Swahili at the landing sites (fishing markets at each location chosen as sampling clusters) using a non-probability approach (i.e. haphazard versus convenience sampling) due to the logistical difficulties of conducting a probability random sample across households that were highly geographically spread in all sampled communities. Due to the survey sampling population being fishers, the best way to sample was to treat market locations as sampling clusters.

Overall, fishers' information was collected from 293 heads of households across 4 regions/islands including Zanzibar Island (Nungwi, n = 51; Mkokotoni, n = 50); Pemba Island (Wesha, n = 50) Tanga on the mainland (Mkinga, n = 50) and Mafia Island (Bweni, n = 42; Kilindoni, n = 50). Economic dependency and associated vulnerability were measured using a standardized household questionnaire containing open-ended, semi-structured, and structured questions designed to document various socio-economic and ecological dimensions across the broad categories of exposure, sensitivity, and adaptive capacity as per Aswani et al. (2018). All ethical requirements were cleared at Rhodes University as well as with our partners in Tanzania prior to field research. The selected survey questions used to collate data (Taylor, 2021) for this study can be found in the Appendix (Table S1).

3.2. Asset Wealth Index (AWI)

Instead of using reported income as a level of wealth indicator this study takes a broader view of living standards and asset ownership. Wealth is complex in nature and the conventional approach to the measurement of wealth/poverty can be limited by only using money-metric income and/or expenditure data, which does not account for the multidimensional nature of wealth/poverty (Maasoumi, 1986; Duclos et al., 2001). A study of wealth can be represented by a rWc matrix with individuals represented in rows (r) and wealth dimensions as represented by columns (c). An effective approach to develop a wealth index in the case of categorical variables, such as in this study, is Multiple Correspondence Analysis (MCA) (Ezzrari and Verme, 2012; Booysen et al., 2008). Similar studies have utilised MCA in creating asset indices (Booysen et al., 2008) and composite wealth indicators (Ezzrari and Verme, 2012).

The Asset Wealth Index (AWI) constructed here contains private income-associated assets as a measurement of individual wealth. The reason being that communal assets may be slower to reflect changes in economic circumstances, while private assets adjust at a faster rate when households improve their ability to afford private assets such as fishing gear. The categorical variables used are drawn from the socio-economic survey regarding house construction materials and assets, water and sanitation, and fishing related assets. The assets reviewed in this survey consider a typical coastal household by including variables such as ownership of a boat or fishing gear. Boat and gear ownership are important indicators of wealth in Tanzanian SSF as boat owners receive a greater share of catch revenue than the vessel crew (Jiddawi and Öhman, 2002). Importantly, the boat ownership variable is categorical to account for the difference in owning a motorised boat that can access more diverse habitats compared to a canoe with limited access.

In this paper we utilise the four-step process of calculating a composite AWI using the MCA as described by Asselin (2009). First, an indicator matrix is created which represents the asset ownership of each individual fisher representing a household as the main livelihood supporter. Secondly, the profiles of the households relative to the categories of asset ownership is calculated. Third, the MCA is then applied to the original indicator matrix which provides a set of category weights from the first dimension (or factorial axis) of the analysis results. Lastly, MCA category weights are applied to the profile matrix. A household's MCA composite indicator score is the sum of that unit's weighted responses.

From this we can construct the functional form of the AWI. With k

representing the number of dimensions (variables) $k = (1, 2, \ldots, K)$, j the number of modalities of each dimension $j = (1, 2, \ldots, J_k)$ and I the binary (0/1) indicator of each modality. W is the category weight based on the MCA, which is the factor score on the first axe normalised by the eigenvalue λ with s equal to the factor score, and i being the index number representing households. Therefore, the AWI can be shown as

$$AWI_i = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k=1}^{J_k} W_{j_k}^{k} I_{j_k i}^{k}$$

with

$$W_{j_k}^{k} = \frac{s^k}{\sqrt{\lambda_1}}$$

3.3. Adaptive capacity

An Adaptive Capacity (AC) score was calculated based on survey questions (Appendix Table S1) around occupational flexibility as a measurement of livelihood diversification potential. Respondents were asked if they felt they would be able to find work in a different sector and how many options they felt they would have for a different type of job. The reason to this approach being that fisheries are impacted by oceanographic changes and biological responses (Cline et al., 2017), which are anticipated to be further impacted by climate change. Occupational diversification and having the ability to shift into different industries are important buffers enabling adaptive capacity for fishers in the event of major shocks and changes within the fishing industry (Allison and Ellis, 2001; Berkes et al., 2001; Fuller et al., 2017).

The questions asked were either binary 'yes/no' or rated from least to most. The yes/no question was given a relative 1 or 0 weighting, and the rated question given weights 0 for no job options, 1 for few options, 2 for some options, and 3 for many options. Therefore, the higher the sum of the answer weights, the higher the adaptive capacity. The lowest attainable score is then 0 and the highest 4. For the regional analysis, the AC scores were then aggregated within the AWI quartiles to assess the average levels of adaptive capacity within the different levels of wealth. The AC scores are therefore calculated as the sum of the fishers' AC scores within each AWI quartile (q) divided by the number of fishers (n) in that specific quartile:

$$AC_q = \frac{\sum A_q}{n_{AWI_q}}$$

3.4. Cross-fishery connectivity

Assessing levels of cross-fishery connectivity within the four regions is a measurement of fishing portfolio diversification. This aims to address the gap in knowledge found by Stoll et al. (2017), being the lack of explicit attention given to the heterogeneity of fishers' connections to fisheries at the level of the individual as an indicator of social and ecological connectivity of fishers. Given the role of SSF in Tanzania providing fishers with both income and food for direct consumption, we illustrate fishers' connections to different species by species targeted for subsistence (consumption) and commercial (sold) purposes. The cross-fishery connectivity is conducted in two parts. Firstly, a cross-fishery connectivity score is calculated at a regional level as the measurement of fishery portfolio diversification within different wealth quartiles. Secondly, radial diagrams are created to show the species groups most dependent upon in the four regions and for what purpose. The diagrams aim to emphasise the connections to fisheries and species at the individual level.

3.4.1. The cross-fishery connectivity score

The cross-fishery connectivity (FC) score is calculated based on the fishers' responses to the species caught for commercial value or purposes, and the species caught for subsistence purposes (Appendix Table S1). The species were grouped into cephalopods, large pelagic, reef, and small pelagic. Each fisher was then assigned a binary (1/0) value in each species group representing whether the fisher targeted a species within that group, or not. The lowest attainable score is therefore 1 and the highest is 4. For the regional analysis, the FC scores are then aggregated within the AWI quartiles to assess the average levels of fishery connectivity within the different levels of wealth. FC within AWI quartiles is calculated as the sum of the fishers' binary values within each AWI quartile (q) divided by the number of fishers (n) in that specific quartile:

$$FC_q = \frac{\sum S_q}{n_{AWI_q}}$$

3.4.2. Cross-fishery connectivity radial diagrams

To measure the connectivity of fishers to different assemblages of fisheries, Fuller et al. (2017) created an association network based on the state and federal licenses that fishers held in Maine, USA. Fisheries in Tanzania operate differently with fisheries being an open-access business and anyone can participate (Juddawi and Ő;hman, 2002). We therefore used the data collected from the survey on what species fishers target for commercial and subsistence purposes to assess the connectivity of fisher to different assemblages of fisheries.

In order to elucidate the overlap in species targeted by different fishers using the radial diagrams, the fisher identification numbers were re-ordered from to the original survey so that those targeting similar species were grouped together. This was done as follows: the total number of connections for each species type (small pelagics, reef, large pelagics, cephalopods) were counted. Then, whichever type had the fewest connections (which happened to be cephalopods in every case) was considered first, and any fisher who targeted these species – either for subsistence or commercially – were grouped, and moved to the start of the list. The same was then done for the species type with the second fewest connections (and so on): all fishers who targeted these, aside from those already re-ordered, were grouped. These were then added to the new list after the first group. Within each group of fishers, the arbitrary original survey order was persevered, aside from the re-ordering described here. Whether a fisher targets a species for commercial or subsistence reasons is not considered during the re-ordering.

Once the fishers had been reordered as described above, the diagrams were produced. For each of the four fisheries (Tanga, Pemba, Zanzibar, Mafia) a diagram was produced showing which fishers target which types of species. The (re-ordered) fisher ID numbers are listed on the bottom semi-circle of each figure, with the four species types at the top. Coloured arcs denote which species each fisher targets.

4. Results

The results show that fishers in all four regions diversify their livelihood strategies, with farming being the most common alternative occupation (Table 1). There is high reliance on fish for nutrition in all four areas as, on average, fishers eat fish six days a week. The frequency of fish being consumed is drastically higher than meat in all four regions. The most prominent method to acquire fish is through own catch. However, a third of fishers in Pemba and Zanzibar rely on a mixed strategy of own catch and purchasing fish from the local market. The percentage of fishers utilising this mixed strategy in Tanga and Mafia is not nearly as high (10% and 12% respectively). These results confirm the high reliance on fish for both livelihood and nutrition security, and show that livelihood diversification is a strategy utilised in fishing communities in Tanzania.

4.1. Asset Wealth Index

The MCA was run using the variables listed in Table 2. The results from the table of eigenvalues (Appendix Table S2) illustrates the

Table 1
Key characteristics of fishers' diet and alternative livelihoods among marine coastal communities of Tanzania.

Region	% of fishers that derive more than 50% of income from fishing	Most common alternative livelihood strategies (% of respondents)	Alternative livelihood sectors willing to move into	Average consumption of food type (days per week)		Method to acquire fish for consumption (% of respondents)		Main risks to fishing livelihoods reported by fishers	Main habitats targeted
Tanga	79%	Farming (50%) and small business (29%)	Livestock and small business	Fish	6	Own catch	88%	Reduced fish abundance, underdeveloped market limiting growth, and environmental change	Deep waters (60%), outer reef, and lagoon reef
				Vegetables	3	Purchase	2%		
				Meat	0.5	Both	10%		
Pemba	88%	Farming (92%)	Aquaculture	Fish	6	Own catch	57%	Reduced fish abundance and too many fishers in the area	Deep waters (73%), outer reef, lagoon reef, mangroves
				Vegetables	3	Purchase	8%		
				Meat	0.6	Both	35%		
Zanzibar	78%	Farming (64%) and small business (18%)	Aquaculture and tourism	Fish	6	Own catch	59%	Reduced fish abundance, environmental change, underdeveloped market limiting growth	Deep waters (85%), outer reefs, and lagoon reefs
				Vegetables	3	Purchase	6%		
				Meat	1	Both	35%		
Mafia	93%	Farming (52%) and small business (30%)	Tourism and service industry	Fish	6	Own catch	83%	Underdeveloped market limiting growth	Deep waters (51%), outer reefs (25%), shallow waters, lagoon reefs, and mangroves
				Vegetables	3	Purchase	5%		
				Meat	1	Both	12%		

superior explanatory power of axis 1 ("Dim" 1 in the table) compared to subsequent axes. This can be seen by axis 1 explaining more than 10.5% of the total inertia of the cloud of variables, compared to axis 2 explaining 5.4% respectively. Hence, we constructed the AWI using the variable weights defined by axis 1 (Table 2).

To test the accuracy of the model, we ensured the MCA results satisfy the properties of the wealth proxies. A higher level of asset wealth is described by the positively correlated indicators, while lower levels of wealth should be described by the indicators negatively correlated to axis 1. The MCA results satisfied these conditions as, for example, owning a flush toilet was weighted at 0.74 while not owning a toilet was −0.58. The extreme values of the AWI were −0.38 for the least wealthy households and 0.78 for the wealthiest households. The AWI weights (Table 2) were then applied and calculated for every fisher's asset portfolio. For example, Fisher ID 1.49 in Zanzibar profiled as house structure made from lime, no boat, long drop, no water tank, no vehicle, no fishing gear, television, no stove, no cell phone, piped water, no refrigerator, no radio, no DVD player, no generator, no electricity, no washing machine, and no solar panel. Applying the AWI weights totals an AWI score of −0.09 and places this fisher in the second lowest wealth quartile.

AWI quartiles were then calculated for each region to assess the adaptive capacity (Section 3.3) and cross-fishery connectivity (Section 3.4) relative to different wealth levels in all four regions. Results of the scores are shown in Table 3.

4.2. Do wealthier Fishers have higher potential to diversify livelihoods?

The study assesses whether wealthier fisheries have more opportunities to diversify livelihoods, as a measurement of adaptive capacity. Higher AC scores (Table 3) reflect the ability to diversify occupations. Based on the average AC scores for each wealth quartile, we find that fishers in the highest wealth quartile in Tanga had the lowest levels of adaptive capacity, while fishers in the second quartile reported the highest levels (Fig. 3a). However, fishers in Pemba (Fig. 3b), Zanzibar (Fig. 3c), and Mafia (Fig. 3d) lend support to the hypothesis as fishers in the higher wealth quartiles reported higher livelihood diversification potential.

4.3. Do wealthier Fishers have more diverse fishing portfolios?

The results reflect the level of fishing portfolio diversification through the FC score results (Table 3). Higher FC scores reflect more diverse fishing portfolios with fishers being connected to multiple groups of species. Wealthier fishers in Tanga (Fig. 3a) had the lowest FC score, therefore targeting fewer species with less diverse fishing portfolios. We see that the other three regions lend support to this hypothesis as wealthier fishers in Pemba (Fig. 3b), Zanzibar (Fig. 3c), and Mafia (Fig. 3d) had higher FC scores reflecting more diverse fishing portfolios.

4.4. Fishery connectivity at the individual level

The radial diagrams (Fig. 4) graphically represent how fishers at the individual level target different groups of species for either commercial or subsistence purposes. From these we see the most commonly targeted species in Tanga for both commercial and subsistence purposes were small pelagics (purple) and large pelagics (green; Fig. 4a and b). It is also evident that the large pelagics overlaped with most other species for both commercial and subsistence purposes. However, there is relatively little overlap between the reef (blue) and small pelagics in both cases. A large portion of fishers only targeted pelagics (large and/or small) for both purposes (fisher nodes 27 to 47).

There appear to be a number of fishers (35%) in Pemba (Fig. 4c and d) who only targeted large pelagics for commercial purposes and not subsistence purposes. These fishers rather target small pelagics and reef fish for consumption instead. Small pelagics appear to be easily accessible as they were largely connected to all other species in many fishers' fishing strategies for both purposes (refer to fisher node 1 to 32). Overall, the most targeted species in Pemba are the large pelagics for commercial purposes and reef species for subsistence purposes.

Large pelagics are extremely important in fishing strategies within Zanzibar (Fig. 4e and f), being the most targeted species for both commercial and subsistence purposes. There is a large group of fishers (20%) who were not connected to many species and rather solely target large pelagic fish for both purposes. The majority of fishers within Zanzibar commonly targeted large pelagic species with reef species.

A large group of fishers (20%) in Mafia (Fig. 4g and h) only target reef species for both commercial and subsistence purposes. Small pelagics held a more prominent role in fishing strategies in Mafia compared to Zanzibar. Overall, reef species are the most commonly targeted for both commercial and subsistence purposes. This is to be expected with outer reefs being one of the most predominant habitats targeted by fishers surveyed in Mafia (Table 1).

Table 2
List of Variables and Modalities for Asset Ownership of Tanzanian Marine Small-Scale Fishers their Relative Multiple Correspondence Analysis Weights.

Variable	Modality	DIM1
House material	Bricks	0.42
	Concrete	0.47
	Lime	−0.58
	Metal	0.00
	Other	−0.56
	Plywood	0.06
	Thatch	−0.45
	Wood	−0.90
Boat	Aluminium boat	1.15
	Dugout	−0.80
	Fibre canoe	−0.38
	Motorised dugout	0.67
	Motorised vessel	1.28
	Ngalawa	−1.16
	No boat	0.01
	Other	0.39
	Outboard motor	0.96
	Ski boat	1.04
Toilet	Composting	0.08
	Flush	0.74
	Long drop	−0.24
	No toilet	−0.58
	Pour flush	0.79
Water tank	No water tank	−0.13
	Water tank	0.87
Vehicle	No vehicle	−0.09
	Vehicle	1.02
Fishing gear	Fishing gear	−0.05
	No fishing gear	0.09
Television	No television	−0.52
	Television	1.25
Stove	No stove	−0.10
	Stove	1.42
Cell phone	Cell phone	0.07
	No cell phone	−0.69
Piped water	No piped water	−0.43
	Piped water	0.53
Refrigerator	No refrigerator	−0.26
	Refrigerator	1.40
Radio	No radio	−0.42
	Radio	0.34
DVD	DVD	1.36
	No DVD	−0.45
Generator	Generator	0.93
	No generator	−0.03
Electricity	Electricity	0.80
	No electricity	−0.52
Washing machine	No washing machine	−0.03
	Washing machine	0.89
Solar panel	No solar panel	0.03
	Solar panel	−0.10

Table 3
Summary of AWI, AC, and FC scores by region for Tanzanian fishing communities.

AWI Quartile	AWI Weight Range	Region	Average AC Score	Average FC Score
Top Quartile	0.15 to 0.59	Tanga	1.33	1.67
		Pemba	1.75	2.42
		Zanzibar	2.13	2.13
		Mafia	2.03	2.2
Third Quartile	- 0.06 to 0.14	Tanga	1.67	2.33
		Pemba	1.89	2.30
		Zanzibar	1.71	1.87
		Mafia	1.45	1.65
Second Quartile	- 0.17 to - 0.07	Tanga	1.89	1.84
		Pemba	1.36	2.30
		Zanzibar	1.06	2.06
		Mafia	1.37	1.78
Bottom Quartile	- 0.31 to - 0.18	Tanga	1.67	1.67
		Pemba	0.94	2.40
		Zanzibar	0.63	2
		Mafia	1.21	1.68

5. Discussion

5.1. Habitat access and market influences on species diversification

Tanga is the only region which rejects the research hypothesis as fishers within the highest wealth quartile had the lowest level of adaptive capacity as well as the lowest level of species diversification. Wealthier fishers in this region had more specialised fishing portfolios targeting fewer groups of species. This is reflected in the individual fishers' portfolios in Tanga as a large portion of fishers only target pelagics, both large and small, for both commercial and subsistence purposes. Perhaps wealthier fishers are able to prioritise targeting specific species over catch success. This could be explained by the most common fishing strategy observed being targeting large pelagics, which include the highly valued tropical tuna and tuna-like species that migrate to Tanzanian waters (Breuil and Grima, 2014).

We also see that a third of the fishers in Pemba only target large pelagics for commercial purposes and not for consumption, and a fifth of fishers in Zanzibar are not connected to many species but rather solely target large pelagic fish for both purposes. In Zanzibar specifically, the large tourism industry influences the market for fish. There is an increased share of high economic value and nutrient-rich fish species that are being absorbed by the tourism and restaurant industry to the detriment of local consumers (Breuil and Grima, 2014). To note in Mafia, there is a surplus of fish that is exported to the mainland (McClanahan et al., 2008) which could incentivise prioritising catch success to participate in the export market. Markets outside of fishing communities are therefore a factor to consider when assessing how and why fishers diversify or specialise their fishing portfolio.

Access to diverse habitats may be impacting the ability to widely diversify fishing portfolios. The multiple habitats reported as part of fishing strategies in Pemba and Mafia could be enabling higher levels of species diversification even for lower wealth quartiles, which is found specifically in Pemba. Mafia is the only region where fishers emphasised targeting habitats in shallow waters. This would be attributed to fishers having restricted access to the eastern side of the island due to the steep continental slope with the fast East African Coastal Current (EACC) close to the shoreline. However, the shallow and sheltered flats between the western side of the island and mainland appear to provide greater access to diverse habitats closer to shore.

Dynamite fishing has damaged coral reefs all along the mainland coast with Tanga being the most affected in the region (Samoilys and Kavange, 2008). This is reflected in the survey results in Tanga as fishers only reported three out of the six possible types of habitats as their most common fishing areas with the majority of fishers relying mainly on deep water habitats. Deep water habitats often require larger and motorised vessels, which are more expensive to own. This could be further limiting diverse habitat access for less wealthy fishers in this region, hence why the lower wealth quartile fishers have low species diversification results. However, it is likely that wealthier fishers also have low species diversification due to the reported underdeveloped markets in Tanga. Limited access to developed markets might incentivise optimisation of fishing efforts to solely target fish that are highly valued in the few markets accessible to fishers in the region to ensure greater financial returns.

5.2. Wealth and livelihood diversification

In all four regions we observed fishers in the lowest asset wealth quartile had low levels of adaptive capacity. This is concerning if fisheries continue to experience volatility and shocks as these fishers feel

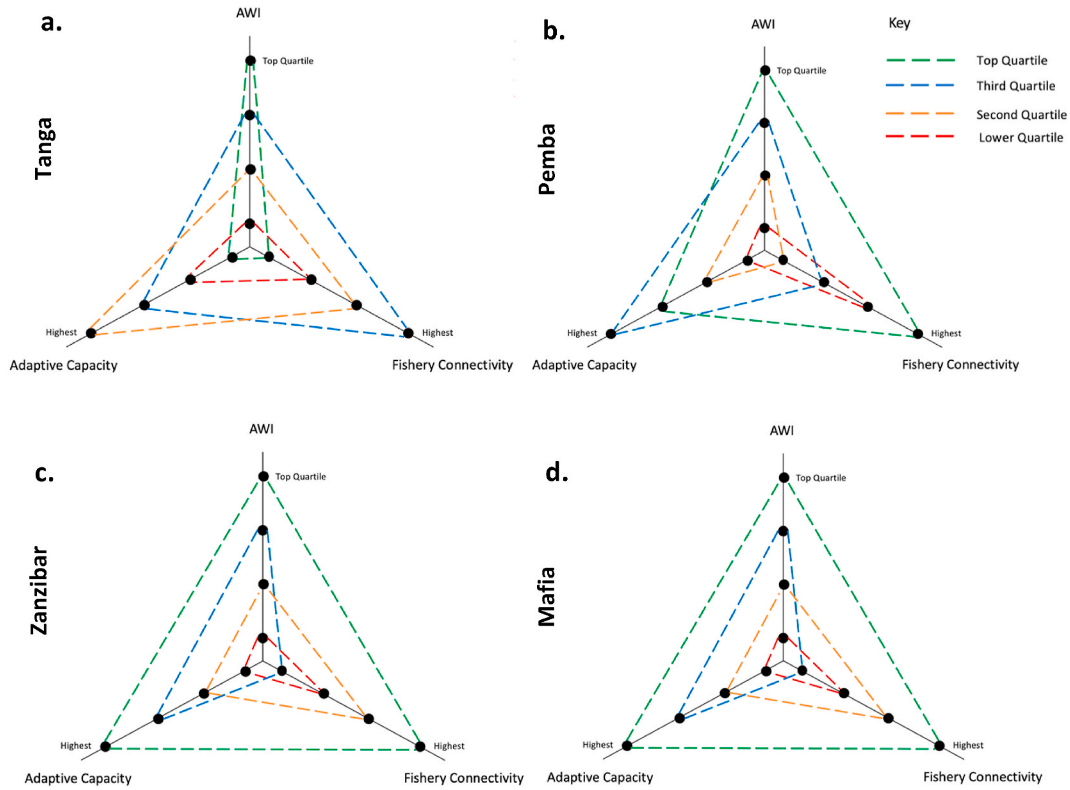

Fig. 3. A graphic representation of the level of connectivity to different species and level of adaptive capacity relative to the AWI wealth quartiles in Tanga (a), Pemba (b), Zanzibar (c), and Mafia (d). The top quartile is represented by the green line, third quartile blue line, second quartile orange line, lowest quartile red line. The results for Tanga reject the research hypothesis shown in Fig. 2. The fishers in Tanga in the highest AWI quartile target fewer species and had the lowest adaptive capacity. The results for Pemba, Zanzibar, and Mafia lend support to the hypothesis with fishers in the highest AWI quartile characterized by the highest levels of connectivity to species and high adaptive capacity. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

they would not be able to find jobs in another industry or sector, and therefore have very few alternative livelihoods. With increasing climate variability (climate change) comes greater vulnerability of fishers (Sainsbury et al., 2018). For example, access to reef species will be temporarily or permanently impacted after coral bleaching episodes (Wagner, 2004). Low adaptive capacity is of particular concern in Mafia as fishers here had the highest reliance on (outer) reef habitats and reef species compared to the other three regions. Further, fishers in Mafia are willing to move into farming or small business but poor soil and low capital investments disable agricultural development and the isolated geographical location of the island restricts the development of business-orientated enterprises (Kulindwa and Lokina, 2013; Rubens and Kazimoto, 2003).

Although a broader set of alternative livelihoods acts as a buffer to economic and environmental volatility or shocks (Allison and Ellis, 2001; Cinner and Bodin, 2010), we found the most common alternative livelihood fishers in all four regions were engaged in is farming. The impact of climate change applies to all resource-dependent livelihoods, albeit in different ways, including terrestrial agriculture. In the case of agriculture, natural disasters such as floods will intermittently impact the access to crops (Levira, 2009; Kangalawe et al., 2017; Ojija et al., 2017). The most common alternative employment sector outside of fishing and farming that fishers in Mafia would be willing to move into was tourism. The majority of fishers in Pemba and Zanzibar would consider working in aquaculture, while most fishers in Tanga would move into small business in the service industry as well as livestock farming and management.

Fishers in the highest wealth quartile in Pemba, Zanzibar, and Mafia had the highest levels of adaptive capacity. However, fishers in the top wealth quartile in Tanga had the lowest adaptive capacity score. This could be attributed to the majority (90%) of men in Tanga coastal communities being engaged entirely in fishing and fish-related business (Mwaipopo and Mahongo, 2020). Fishers in Tanga reported one of the main threats to fishing livelihoods being underdeveloped markets in the area limiting small business growth. Although it would be assumed that wealthier fishers would have more options to diversify livelihoods, we see that fishers feel the underdeveloped and fishing-centric market may be limiting the ability the diversify occupations outside of the fishing sector regardless of wealth.

Zanzibar had the lowest average income per month from all sources of employment and the highest presence of credit as a method to access food that is not personally grown or caught. A total of 11% of fishers used credit to purchase food in Zanzibar, which is higher than the other regions with less than 5% of fishers relying on credit. This could be due to Zanzibar being the most common island for tourists to visit in Tanzania which has implications such as an increase the general cost of living during high tourism season in this region (UNICEF, 2018). The majority of fishers in Zanzibar are involved in crop farming, however only 28% of fishers would want to move into farming full-time if they could no longer fish. Responses to this scenario were quite diverse including moving into the tourism industry, starting a small business, and construction work. The variety of responses could reflect more diverse industry and available work in Zanzibar compared to the other islands. However, even with a more diverse economy a fifth (20%) of the fishers felt they would have no other options and would have to rely on family to support them if they were no longer able to fish.

6. Conclusions

This study shows the complex relationship between fishers' wealth,

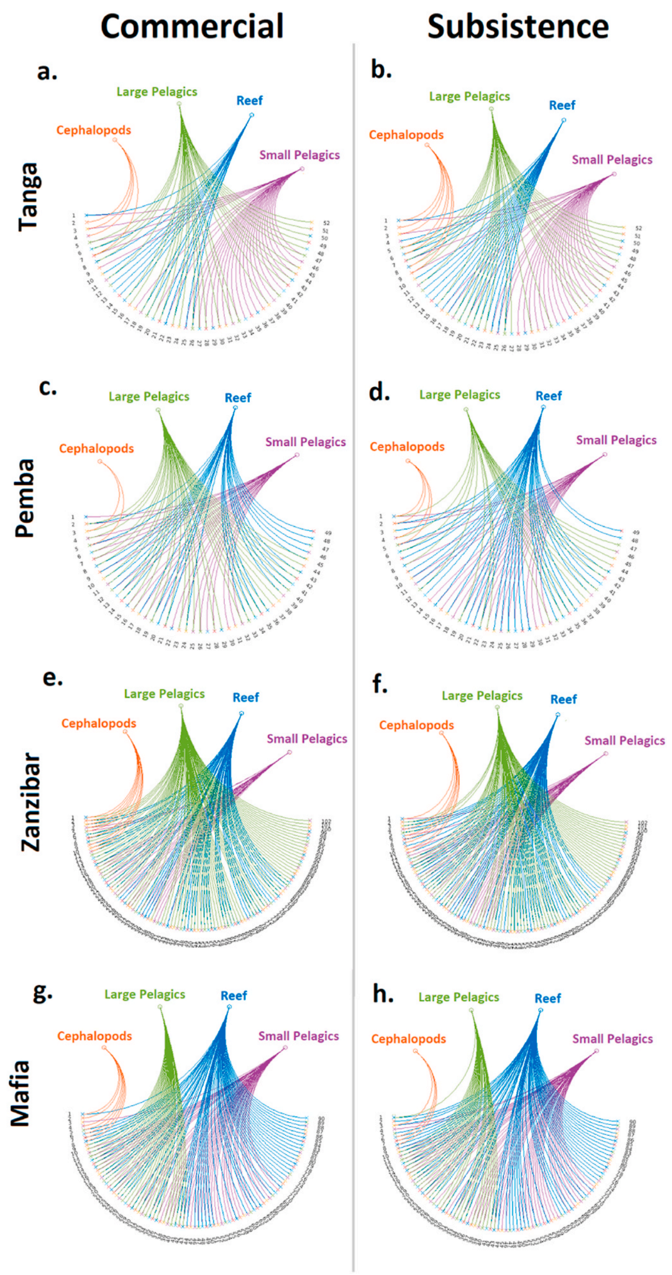

Fig. 4. Radial diagrams highlighting the overlap in species targeted by fishers surveyed in Tanga (a and b), Pemba (c and d), Zanzibar (e and f) and Mafia (g and h). Commercial fishing shown in the left plots, subsistence fishing shown on the right. In each subplot, the numbers on the bottom half correspond to specific fishers (for each fishery, fisher N corresponds to the same person in both the commercial and subsistence plots). Fishers who target cephalopods, large pelagics, reef fish and small pelagics are shown with orange, green and blue arcs respectively. Fishers were re-reordered as described in Section 3.4.2 to highlight the overlap in which species are targeted. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

species diversification, and self-reported adaptive capacity in tropical fisheries. The relationships between these three variables (wealth, adaptive capacity, and fishery connectivity) are circumstantial within the scope of this study and require further statistical analysis to observe the nature of the linkages. However, it is interesting to note the way in which fishers within different wealth quartiles (a) perceive their level of adaptive capacity and (b) how they connect to fisheries.

We find that the portfolio strategies of wealthier fishers in Pemba, Zanzibar, and Mafia were more diverse and had some of the highest levels of adaptive capacity within these regions. The results in these three regions align with previous findings in tropical fisheries (Robinson et al., 2020). Fishers in lower wealth quartiles had less diverse fishing portfolios, which could be fishers choosing species specialisation as a fishing strategy. However, this could be due to low levels of wealth limiting ownership of gear, as fishers who do not own gear in Tanzania earn less of the catch revenue compared to the boat/gear owners (Jiddawi and Öhman, 2002). Access to diverse habitats will maximise catch diversity and potentially help increase adaptive capacity, ensure nutritional security, and protect livelihoods (Robinson et al., 2020). Being in a lower level of asset wealth could be restricting greater financial returns, which would enable the option of gear and species diversification. The limitations to boat and diverse gear ownership should therefore be acknowledged in management strategies promoting catch diversification in tropical fisheries.

Interestingly, we find that wealthier fishers in Tanga opted for species specialisation and had the lowest levels of adaptive capacity within the region. This could be attributed to fishers in Tanga generally targeting fewer types of habitats compared to the diversity of habitats in the other three regions. This elucidates the influence of habitat access on fishing portfolio diversity, as the reefs in Tanga have been the most affected by dynamite fishing in the mainland coastal region (Samoilys and Kavange, 2008).

In all four regions we observed fishers in the lowest asset wealth quartile had low levels of adaptive capacity. This is concerning with increasing climate variability further increasing the vulnerability of fishers (Sainsbury et al., 2018). Although a broader set of alternative livelihoods acts as a buffer to economic and environmental volatility or shocks (Allison and Ellis, 2001; Cinner and Bodin, 2010), we found the most common alternative livelihood fishers in all four regions were engaged in was farming which is equally impacted by climate change albeit in different ways (Levira, 2009; Kangalawe et al., 2017; Ojija et al., 2017). It may be of importance for development strategies to note the most common alternative employment sectors outside of fishing that fishers are willing to move into. Fishers in Mafia would be willing to move into tourism, the majority of fishers in Pemba and Tanzania would consider working in aquaculture, while most fishers in Tanga would move into small business in the service industry as well as livestock farming and management. These alternative livelihood preferences could be useful insights highlighting potential areas for skill development initiatives as well as alternative industries to develop and invest in as ways to increase adaptive capacity of fishers in these coastal communities.

Our findings also highlight an awareness of fishers to the prevailing risks they face. The most predominant risks to fishing as a primary occupation were overcrowding of fishers in the area, reduced fish availability (largely linked to the presence of industrial fishing), market constraints, and environmental change. It is encouraging here that the Tanzania Agriculture Food Security Investment Plan (TAFSIP) 2011–2021 acknowledges market constraints, i.e. weak economic and infrastructure market linkages, as one of the five factors attributing to this disconnect between economic growth and improving food security (United Republic of Tanzania, 2011). In fact, a third of the fishers within our study confirmed market constraints as the biggest risk to fishing livelihoods within coastal communities. Market prices are also a factor to consider specifically within Zanzibar where there is an increased share of high economic value and nutrient-rich fish species that are being absorbed by the tourism and restaurant industry to the detriment of local consumers (Breuil and Grima, 2014).

Another challenge to food security in Tanzania acknowledged in the TAFSIP (United Republic of Tanzania, 2011) is the low availability and consumption of nutritious foods, such as fish, in both the mainland and Zanzibar household diets. Studies by Cochrane and D'Souza (2015) and Ochieng et al. (2017) found a significant lack of diversity in diets and insufficient intake of foods rich in micronutrients within Tanzanian households. In contrast, our results showed diversity in diet with a high (six times a week) intake of fish as a highly nutrient-dense food source. Overall, these results emphasise the important role that fisheries play in maintaining food security within coastal communities of Tanzania by ensuring nutrient-dense food availability from catch.

Finally, the information we gathered in this study may be important for fisheries policies and management of marine areas. Species diversification is often offered as an adaptation strategy to increase the resilience of these fisheries to natural and economic shocks. Less wealthy fishers in isles of Zanzibar, Pemba, and Mafia tend to target fewer species, making them less able to absorb changes in management measures which may be species or area focused. Likewise, those with higher wealth scores and higher adaptive capacity will be able to better absorb the short-term losses of fishery closures when compared to those with lower wealth and adaptive scores who rely on higher levels of fishery connectivity. However, we observe that fishers targeting multiple species are not always the most financially secure or able to adapt to shocks in the fishery industry. The results in the mainland coastal region of Tanga show different fishing behaviour in different wealth quartiles compared to the other regions, which is a case for region specific analyses when promoting species diversification strategies in tropical fisheries.

Author contributions

ST was the lead author and responsible for coordination of all contributions. SA and NJ contributed to the development of the paper framework and contributed to sections 4 and 5. JC coordinated the data collection vital to the survey analysis within the paper. PJ coordinated section 3.2, contributed to sections 4 and 5, and made important contributions to the framework of the paper. SK contributed to section 3.4, to the development of the radial diagrams, and section 4. HK was involved in data collection, translations, and contributed to section 5. MR contributed to sections 4 and 5. EP contributed to the development of the radial diagram method and analysis of the results.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgements

This publication was produced with the financial support of the Global Challenges Research Fund (GCRF) in the framework of the SOLSTICE-WIO project, NE/P021050/1. We would like to acknowledge the team responsible for the survey work carried out in Tanzania led by Shankar Aswani and Narriman Jiddawi: Khamis Hassan, Maryam Abeid and Ali Rashid, Ramadhan Rashid, Frank Mirobo, Amana Pandu, Nassoro Katunda, Tumbu Ladislaus, Idris Kweweta, Filbert Msafiri and Secilia Tarama, Rose Mwaipopo, Jack Coupland, Brian Khumalo, Yvette Le Fleur and Amber Smith, Lebogang Kibane, and Rinisa Naidoo, and overall project logistics coordination by Sofia Alexiou. Survey data used in this study available at Mendeley Data under the title "Tanzanian Small-Scale Fisheries Survey Data" https://doi.org/10.17632/jnxhwjzywp.1.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105808.

References

Allison, E.H., Ellis, F., 2001. The livelihoods approach and management of small-scale fisheries. Mar. Pol. 2 (25), 337–388.
Allison, E.H., Horemans, B., Bene, C., 2006. Vulnerability reduction and social inclusion: strategies for reducing poverty among small-scale fisherfolk. In: Wetlands, Water and Livelihoods Workshops, Wetland International. January 30 - February 2, St. Lucia, South Africa.
Anderson, S.C., Ward, E.J., Shelton, A.O., Adkison, M.D., et al., 2017. Williams, Benefits and risks of diversification for individual Fishers. Proc. Natl. Acad. Sci. U.S.A. 114, 10797–10802.
Asselin, L.M., 2009. Analysis of multidimensional poverty: theory and case-studies. In: Economic Studies in Inequality, Social Exclusion and Well-Being, Volume No. 7. Springer.
Aswani, S., Lemahieu, A., Sauer, W.H.H., 2018. Global trends of local ecological knowledge and future implications. PloS One 13, e1095440.
Bell, J.D., Cisneros-Montemayor, A., Hanich, Q., Johnson, J.E., et al., 2018. Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. Mar. Pol. 88, 303–314.
Berkes, F., Mahon, R., McConney, P., Pollnac, R., Pomeroy, R., 2001. Managing Small-Scale Fisheries: Alternative Directions and Methods, first ed. International Development Research Centre, Ottawa.
Booysen, F., van der Berg, S., Burger, R., et al., 2008. Using an asset index to assess trends in poverty in seven sub-Saharan African countries. World Dev. 36 (6), 1113–1130.
Breuil, C, Bodiguel, C, 2015. Report of the meeting on marine small pelagic fishery in the United Republic of Tanzania. SFFAO/2015/34. IOC-SmartFish Programme, FAO.
Breuil, C., Grima, D., 2014. In: Baseline Report Tanzania. SmartFish Programme of the Indian Ocean Commission, Fisheries Management FAO component, Ebene, Mauritius, p. 43.
Cinner, J.E., Bodin, O., 2010. Livelihood diversification in tropical coastal communities: a network-based ap- proach to analyzing 'livelihood landscapes. PloS One 5, e11999. https://doi.org/10.1371/journal.pone.0011999.PMID:20711442.
Cline, T.J., Schindler, D.E., Hilborn, R., 2017. Fisheries portfolio diversification and turnover buffer Alaskan fishing communities from abrupt resource and market changes. Nat. Commun. 8, 14042.
Cochrane, N., D'Souza, A., 2015. Measuring Access to Food in Tanzania: A Food Basket Approach, EIB-135. U.S. Department of Agriculture, Economic Research Service. February 2015.
Duclos, J.-Y., Sahn, D., Younger, S., 2001. Robust multi-dimensional poverty comparisons. Econ. J. 116 (514), 943–968.
Ezzrari, A., Verme, P., 2012. A Multiple Correspondence Analysis Approach to the Measurement of Multidimensional Poverty in Morocco, 2001–2007. Policy Research Working Paper 6087. The World Bank, Washington, DC.
FAO, 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in Action. https://doi.org/10.4060/ca9229en. Rome.
Feidi, I.H., 2005. The fisheries of zanzibar: potential for new investments. NAGA, WorldFish Center Quartely 28. No. 3&4, July - December 2005. Vol. 28. WorldFish Center, 28 November 2012.
Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockström, J., 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecol. Soc. 15 (4).
Francis, J., Bryceson, I., 2001. Tanzanian coastal and marine resources: some examples illustrating questions of sustainable use. In: Lessons Learned: Case Studies in Sustainable Use, pp. 76–102.
Fuller, E.C., Samhouri, J.F., Stoll, J.S., Levin, S.A., Watson, J.R., 2017. Characterizing fisheries connectivity in marine social– ecological systems. ICES J. Mar. Sci. 74, 2087–2096.
Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Global Environ. Change 15, 199–213.
Harrison, P.J., 2010. In: Entrenching Livelihoods Enhancement and Diversification into Marine Protected Area Management Planning in Tanga, Tanzania. IUCN ESARO, Nairobi, Kenya, p. 95.
Horrill, J.C., Kamukuru, A.T., Mgaya, Y.D., Risk, M., Church, J., 2000. Northern Tanzania, zanzibar and Pemba. In: McClanahan, T.R., Sheppard, C., Obura, D.O. (Eds.), Coral Reefs of the Western Indian Ocean: Their Ecology and Conservation. Oxford University Press, New York.
January, M., Ngowi, H.P., 2010. Untangling the Nets: the Governance of Tanzania 's Marine Fisheries (Research Report 5). South African Institute of International Affairs, Johannesburg, pp. 1–59.
Jiddawi, N.S., Öhman, M.C., 2002. Marine fisheries in Tanzania. AMBIO A J. Hum. Environ. 31 (7), 518–527. https://doi.org/10.1579/0044-7447-31.7.518.
Kangalawe, R.Y.M., Mung'ong'o, C.G., Mwakaje, A.G., Kalumanga, E., Yanda, P.Z., 2017. Climate change and variability impacts on agricultural production and livelihood systems in Western Tanzania. Clim. Dev. 9 (3), 202–216. https://doi.org/10.1080/17565529.2016.1146119.
Kasperski, S., Holland, D.S., 2013. Income diversification and risk for fishermen. Proc. Natl. Acad. Sci. U. S. A. 110, 2076–2081.
Kizenga, H.J., 2020. Primary Productivity and Small Pelagic Fish Catches along the Western Coast of Pemba Island. Master's Thesis, University of Dar es Salaam, p. 96.
Kulindwa, K., Lokina, R., 2013. Winners and losers in the finfish trade on Mafia island: a value chain analysis. West. Indian Ocean J. Mar. Sci. 12 (2), 151–168.
Kurien, J., López Ríos, J., 2013. Flavouring Fish into Food Security. FAO-SmartFish Programme of the Indian Ocean Commission, Ebene, Mauritius. Report/Rapport: SF-FAO/2013/14. August/Aout 2013.
Leach, V., Kilama, B., 2009. Institutional analysis of nutrition in Tanzania. In: Dar Es Salaam: Research on Poverty Alleviation (REPOA). Special Paper 0931.

Levira, P.W., 2009. IOP Conf. Ser. Earth Environ. Sci. 6, 372049.
Maasoumi, E., 1986. The measurement and decomposition of multidimensional inequality. Econometrica 54, 771–779.
MacNeil, M.A., Graham, N.A.J., Cinner, J.E., Dulvy, N.K., et al., 2010. Transitional states in marine fisheries: adapting to predicted global change. Philos. Trans. R. Soc. Lond. B Biol. Sci. 365, 3753–3763.
McClanahan, T., Cinner, J., Kamukuru, A., Abunge, C., Ndagala, J., 2008. Management preferences, perceived benefits and conflicts among resource users and managers in the Mafia Island Marine Park, Tanzania. Environ. Conserv. 35 (4), 340–350. Retrieved March 30, 2021, from. http://www.jstor.org/stable/44520364.
Mwaipopo, R., Mahongo, S.B., 2020. Adaptive capacity of small pelagic fishing communities in coastal Tanga (Tanzania) to changes in climate-related phenomena. WIO Journal of Marine Science Special Issue 1, 127–144.
Ngusaru, A.S., Tole, M.P., 2001. Comparison of the Classification of the East African Coastline Habitats Using Loiczview Clustering Tool and Expert Knowledge of the Area.
Obura, D., 2004. Biodiversity Surveys of Hard Corals (Scleractinia) in the Mafia Island Marine Park, Tanzania. CORDIO East Africa.
Ochieng, J., Afari-Sefa, V., Lukumay, P.J., Dubois, T., 2017. Determinants of dietary diversity and the potential role of men in improving household nutrition in Tanzania. PloS One 12 (12), e0189022. https://doi.org/10.1371/journal.pone.0189022.
Ojija, F., Abihudi, S., Mwendwa, B., Leweri, C., Chisanga, K., 2017. The impact of climate change on agriculture and health sectors in Tanzania: a review. Environment. Agriculture and Biotechnology 1758–1766.
Osterblom, H., Crona, B.I., Folke, C., Nystrom, M., Troell, M., 2016. Marine ecosystem science on an intertwined planet. Ecosystems. https://doi.org/10.1007/s10021-016-9998-6.
Robinson, J.P.W., Robinson, J., Gerry, C., Govinden, R., Freshwater, C., Graham, N.A.J., 2020. Diversification insulates Fisher catch and revenue in heavily exploited tropical fisheries. Science Advances 6 (8), eaaz0587.
Rubens, J., Kazimoto, S., 2003. Application of the WCPA-Marine/WWF Guidebook on Evaluating Effective Management in MPAs: Mafia Island A Demonstration Case. IUCN Publications Services Unit.
Sainsbury, N, Genner, M, Saville, G, et al., 2018. Changing storminess and global capture fisheries. Nat. Clim. Change 8, 655–659. https://doi.org/10.1038/s41558-018-0206-x.
Salmi, P, 2005. Rural pluriactivity as a coping strategy in small-scale fisheries. Sociol. Rural. 45, 22–36.
Samoilys, M.A., Kanyange, N.W., 2008. Natural Resource Dependence, Livelihoods and Development: Perceptions from Tanga, Tanzania. IUCN ESARO.
Sekadende, B., Scott, L., Taylor, S.F.W., et al., 2020. The small pelagic fishery of the Pemba Channel, Tanzania: what we know and what we need to know for management under climate change. Ocean Coast Manag. 197, 105322 https://doi.org/10.1016/j.ocecoaman.2020.105322.
Semba, M., Kimirei, I., Kyewalyanga, M., Peter, N., Brendonck, L., Somers, B., 2016. The decline in phytoplankton biomass and prawn catches in the Rufiji-Mafia Channel, Tanzania. West. Indian Ocean J. Mar. Sci. 15 (1), 15–29.
Sethi, S.A., Reimer, M., Knapp, G., 2014. Alaskan fishing community revenues and the stabilizing role of fishing portfolios. Mar. Pol. 48, 134–141.
Silas, M.O., Mgeleka, S.S., Polte, P., Sköld, M., Lindborg, R., De La Torre-Castro, M., Gullström, M., 2020. Adaptive capacity and coping strategies of small-scale coastal fisheries to declining fish catches: insights from Tanzanian communities. Environ. Sci. Pol. 108, 67–76.
Stoll, J.S., Fuller, E., Crona, B.I., 2017. Uneven adaptive capacity among Fishers in a sea of change. PloS One 12 (6), e0178266. https://doi.org/10.1371/journal.pone.0178266.
Taylor, S.F.W., Roberts, M.J., Milligan, B., et al., 2019. Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis? Food Sec 11, 1395–1415. https://doi.org/10.1007/s12571-019-00971-6.
Taylor, S.F.W., 2021. Tanzanian small-scale fisheries survey data. Mendeley Data V1. https://doi.org/10.17632/jnxhwjzywp.1. Available Online: https://data.mendeley.com/datasets/jnxhwjzywp/1.
UNICEF, 2018. Assessment of the impact of tourism on communities and children in zanzibar. Available Online: https://www.unicef.org/tanzania/sites/unicef.org.tanzania/files/2019-12/Tanzania-Impact-of-Tourism-Zanzibar-2019.pdf. (Accessed 15 March 2020).
United Republic of Tanzania, 2011. Tanzania agriculture and food security investment plan (TAFSIP). Available Online: https://www.grain.org/media/W1siZiIsIjIwMTMvMDIvMjgvMTRfNDJfMTFfODBfVGFuemFuaWFfQ0FBRFBfUG9zdF9Db21wYWN0X0ludmVzdG1lbnRfUGxhbi5wZGYiXV0. (Accessed 15 March 2020).
van Hoof, L., Kraan, M., 2017. Mission Report Tanzania; Scoping Mission Marine Fisheries Tanzania. Wageningen Marine Research (University & Research centre, Wageningen, p. 66pp. Wageningen Marine Research report.
Wagner, G.M., 2004. Coral reefs and their management in Tanzania. West. Indian Ocean J. Mar. Sci. 3 (2), 227–243.
Young, T., Fuller, E.C., Provost, M.M., Coleman, K.E., St Martin, K., McCay, B.J., Pinsky, M.L., 2019. Adaptation strategies of coastal fishing communities as species shift poleward. ICES J. Mar. Sci. 76, 93–103.