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Using fishers' local ecological knowledge for management of small-scale fisheries in data-poor regions: Comparing seasonal interview and field observation records in East Africa

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ABSTRACT

Fishers, scientists and policy makers need to describe, understand and "agree on" variations in fish catches caused by exploitation and climate change for effective fisheries management. To achieve this, relevant data with sufficient spatiotemporal resolution is a necessity. In regions of the Global South, such as the Western Indian Ocean (WIO), fish catch data useful for management is scarce or non-existing. Still, the potential of local ecological knowledge to provide such information has not been fully utilised in these regions. In this study, we evaluated fishers' local ecological knowledge (based on interviews) against detailed seasonal fish catch variability data based on catch per unit effort (CPUE) records. Because of the importance of the monsoon seasons for marine resource variability, differences in fish catches during the northeast (NE) and southeast (SE) monsoon seasons were investigated. Fishers' perceptions generally agreed with catch data records, both showing that the NE monsoon season generally provides higher catch rates than the SE monsoon season. The fishers' perceptions at two of the landing sites (Nyamisati and Shangani) contradict the recorded observations by showing highest fish catches during the SE monsoon season. It was clear, however, that fishers' perceptions in these two sites focused on the most valuable target species (prawn and tuna in Nyamisati and Shangani, respectively) rather than total catches. In this particular case, fishers' perceptions facilitated the significance of taking target species into consideration. The findings of this study highlight the importance of integrating local ecological knowledge into scientific research to help understand the complex dynamics of coastal fisheries and improve the management of data-poor fisheries.

1. Introduction

Today's overexploitation of marine fisheries alongside environmental changes and extreme climatic events pose significant threats to fish stocks, biodiversity, and ecosystem functioning, and hence the livelihoods and food security of millions of people globally (Cheung et al., 2013; Costello, 2017; IPCC, 2021). One of the challenges of managing fisheries resources is understanding variations in fish catches at different spatiotemporal scales, but this is rarely considered in the literature (but see e.g. Ban et al., 2017, Daw et al., 2011), and hardly at all for East African small-scale fisheries.

Numerous studies worldwide have investigated fish caught by local, small-scale fishers (Ayilu et al., 2022; Fulton et al., 2019). In the Western Indian Ocean (WIO) region, most quantitative studies on small-scale fisheries have used annual countrywide total landed fish weights as a proxy for fish abundance (Jacquet et al., 2010; Jafar-Sidik et al., 2010; Jebri et al., 2020), while few studies have considered fishing effort in terms of catch per unit effort (CPUE) as a measure of fish abundance, and these are limited to coastal bays (Lugendo et al., 2007; Mwandya et al., 2010). Although these studies provided local information on fish

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landings, their findings cannot fulfil the requirements for generalising catch patterns over larger coastal areas. Total landed weight has been used for decades as a measure of fishing performance, but it is unsuitable for determining regional catch patterns as catches vary across time, space and conditions, and need to be standardised with fishing effort (McClanahan, 1988; McClanahan and Cinner, 2012; Thoya and Daw, 2019). For example, few artisanal fishers reach their main fishing grounds during bad weather conditions (Thoya and Daw, 2019).

Fishers' local ecological knowledge (LEK) can provide long-term insight into catch trends and their relation to various climate and environmental parameters (Hind, 2014). If comparable, fishers' LEK could provide important complementary information required for managing data-poor fisheries, and perhaps offer a shortcut to information needed for scientific research (Hind, 2014; Reid et al., 2021; Stephenson et al., 2016; Tobisson et al., 1998). An example emphasising the relevance of fishers' LEK is from British Columbia, Canada, where the abundance of crabs started to decrease in some local coastal areas in the 1990s. Fishers rapidly became aware of the decline, while federal managers did not detect this crab reduction because local variations were masked in regional data used for management (Ban et al., 2017). The local decline of crabs would hence have been seen much earlier if community experience had been integrated with fisheries research and management. Using local knowledge in resource management has been recognised as a management tool in many areas, including fisheries, forestry, irrigation schemes and climate adaptation (notably by Nobel Laureate Elinor Ostrom). Knowledge provided by local appropriators, who have intimate knowledge of a resource and climatic conditions, can be important input into managing and monitoring common-pool resources such as fish stocks (Ostrom, 2005) and in building capacity to prevent resource over-exploitation (Ostrom, 1990) or biodiversity loss.

In Tanzania, climatic conditions vary along the extensive coastline. In the WIO region, the differences between the northeast (NE) monsoon season (May to October) and the southeast (SE) monsoon season (November to April) have strong effects on weather and associated sea surface temperature (SST), rainfall patterns, and river discharge rates (Kizenga et al., 2021; McClanahan, 1988; Semba et al., 2019). These changes over the seasons are related to the annual variations of the Intertropical Convergence Zone (ITCZ), which also regulate the wet and dry seasons (Ongoma and Chen, 2017). Understanding how these factors are associated with fish catch is essential for sustainable fisheries management. The knowledge of the influence of oceanographic and weather conditions on fish landings in the WIO region is largely biased towards

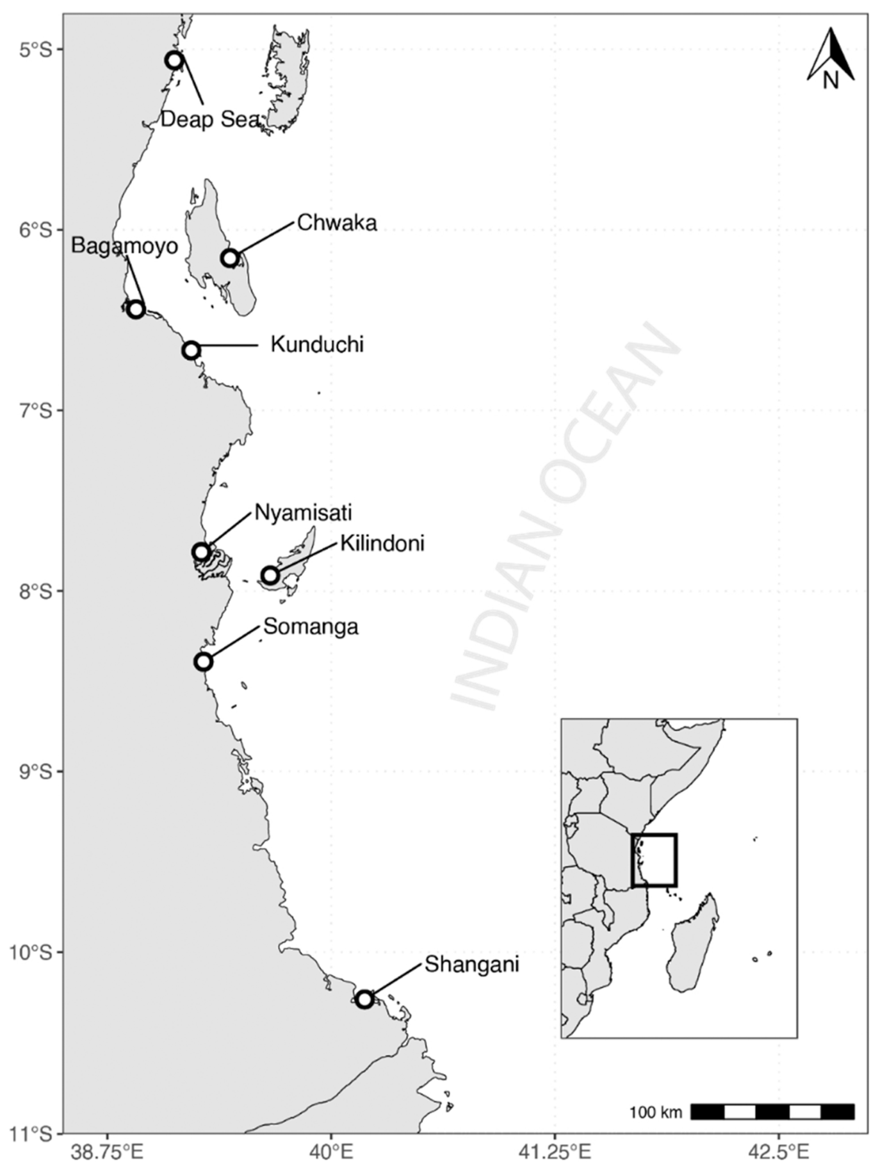

Fig. 1. Location of fish landing sites along the coastal waters of Tanzania. The inset map shows the location of the Tanzanian coast in the WIO region.

data from oceanic pelagic fishes and coral reef fish populations (Kizenga et al., 2021; Samoilys et al., 2019; Sekadende et al., 2020), while there is limited information regarding fish landings from many other seascape environments.

In this study, we examined the role of fishers' LEK in fisheries management by comparing fish catch data covering eight major landing sites along coastal Tanzania with interview data from local fishers. The aim was to understand if fishers' LEK matches and complements fish catch statistics. Our research questions were: (1) To what extent do fishers' perceptions compare with observed fish catch data sampled over a year-cycle along the coast in relation to weather parameters? (2) Which factors do fishers mention to be most important for variability in fish abundance and how have these factors affected marine harvest? and (3) How can LEK complement detailed catch data and contribute to more effective and sustainable management of data-poor fisheries?

2. Method

2.1. Study area

The field sampling of this study was conducted in different areas along the 1424 kilometres (Ngusaru et al., 2001) long coastal stretch of Tanzania (Lat. 5.5º–10.5º S; Long. 38.7º–40.5º E; Fig. 1). Eight landing sites were selected based on geography (i.e. one major fish landing hub in each coastal district), intensity of fishing activities, presence of local fishers and accessibility by road, and included Deep Sea, Chwaka, Bagamoyo, Kunduchi, Nyamisati, Kilindoni, Somanga and Shangani (Fig. 1). Trade winds affect weather and climate of Tanzania during the monsoons along with their periodical changes in strength and direction (McClanahan, 1988). The changes in weather and climatic conditions result in two major seasons; the southeast (SE) monsoon season, which commonly occurs between May and October, and the northeast (NE) monsoon season that usually begins in November and ends in April. The SE monsoon is characterised by relatively low air temperatures, high precipitation, strong winds from the southeast, rough seas, and a deep thermocline associated with high-water column mixing (Mahongo et al., 2012; McClanahan, 1988). In contrast, the NE monsoon is characterised by higher air temperatures, low precipitation, weak winds from the northeast, calm seas, and a shallow stable thermocline associated with low-water column mixing (McClanahan, 1988). Additionally, the north-flowing East Africa Coastal Current (EACC) affects the physical and chemical properties of the coastal waters of Tanzania (Jacobs et al., 2021; Obura et al., 2019; Semba et al., 2019), causing low nitrogen levels in the surface waters and high (>25 °C) sea surface temperature (SST) (Painter, 2020).

2.2. Data sources

The field-study period was 2013–2014 and included recollections of fishers' perceptions of seasonal catch variations (collected in 2016 through questionnaire interviews), fish catch and effort data (from 2013 to 2014), and monthly SST and river discharge data from the same period. SST and river discharge were used to assess their influence on tuna and prawn catches, respectively, because they are among the main environmental factors driving catch variability in the coastal waters of the Western Indian Ocean. In addition, the same factors are linked to marine fish re-distribution and migration in major oceans (Cheung et al., 2012; IPCC, 2021; Perry et al., 2005).

2.3. Questionnaire data

We collected data using a questionnaire to understand fishers' perceptions of seasonal catch variations in semi-structured interviews administered randomly to fishers at the eight premeditated landing sites between January and March 2016, (see Fig. 1, Table 1). The interviews were hence carried out two years after the fish data collection (see *2.2.2. Fish sampling data*), which was perceived as a minor issue because the questionnaire and interviews explored general fishers' experiences. Before the interviews, meetings were carried out with fisheries officers, beach recorders and the local Beach Management Unit to introduce the study, clarify any conflicts or vested interest that might affect fishers' perceptions (Daw et al., 2011) and ask for their cooperation. Our study also developed a credible relationship between scientists and fishers five days before administering questionnaires by visiting landing sites to get familiarised with the interviewees. Some of the questions addressed subjects like the seasons with high or low fish catches, when fishers appear to catch the most fish, and what ecological factors they believe are responsible for these trends. The details of the interview method (including the list of questions asked) are described in Silas et al. (2020).

Table 1
Numbers of interviewed fishers from the studied landing sites in Tanzania (N = 319).

Landing site	District	Region location	No. respondents
Deepsea	Tanga	Tanga	49
Bagamoyo	Bagamoyo	Pwani	45
Kunduchi	Kinondoni	Dar es Salaam	34
Nyamisati	Rufiji	Pwani	38
Somanga	Kilwa	Lindi	43
Shangani	Mtwara	Mtwara	37
Kilindoni	Mafia	Pwani	50
Chwaka	Unguja kati	Zanzibar	23

The findings derived from the questionnaires were compared with catch statistics data to examine if they matched. Despite the trust usually put on scientific data for validation, these data are also subject to potential inaccuracies due to poor resolution, biases and incorrect assumptions (Charles, 1998; Chen et al., 2003). Therefore, we assessed and compared social perceptions of fish catch data collected in this study through interviews with fisheries statistic records (gathered from the Fisheries Department) to better understand fisheries catch dynamics.

2.4. Fish sampling data

Catch and effort data were collected from the small-scale fisheries at the eight selected landing sites from June 2013 to April 2014. We visited the landing sites every second month during this period and collected fish catch and effort data during eight days (evenly spread across the lunar cycle of the sampled months) from three similar types of vessels with fishers using a certain gear type (e.g. gillnet). The procedure was repeated for all available gears at the different landing sites (noteworthy, the number and types of gears differed among the different sites). The number of fishers and fishing time were also recorded. The landed fish weight (in total and separately for each target species) from each boat was split into portions, hereafter referred to as a sample. However, when the number of caught fish from a boat was limited and easy for researchers to handle, the landed fish weight was used as a measure. A sample of landed fish was wet-weighed using a 100 kg scale. Furthermore, fisheries-related information like time of departure from the fish landing site (or fishing ground) and arrival to the fishing ground (or landing site) was recorded for each vessel.

2.5. Catch assessment data

Catch assessment surveys (CASs) are devoted surveys targeting the capture fisheries to gather information on fish catches and fishing efforts (MLFD, 2018b). Catch assessment data were obtained from the Ministry of Livestock and Fisheries (https://smartcas.net/ecas/). As a complement to the bimonthly data collected during the survey 2013–2014, we further explored sites with contrasting patterns of catch distribution with the help of monthly catch distribution data. CAS data comprised 106 landing sites along the seventeen coastal districts of Tanzania, however, only fish catch and effort data from the eight selected landing sites (Fig. 1) were used in this study.

2.6. Oceanographic data and river discharge

Monthly SST data, with a horizontal resolution of 4 km, were acquired by images of the moderate resolution imaging spectroradiometer (MODIS) sensor. To match with the fisheries data, SST data were described for the seascape area (ca 15 km in diameter) surrounding each study site (Fig. 1) and included data from June 2012 to June 2021 that were downloaded from NASA (http://modis.gsfc.nasa.gov). Only data covering the field study period (i.e. June 2013 to April 2014) was used for analysis. Daily discharge data of the major rivers (including Rufiji) were extracted from the Hydrological Year Book of Tanzania (https://www.maji.go.tz/). River discharge was a proxy for rainfall and measured in cubic meters per second (m^3/s). The Hydrological Year Book has data covering the period June 2010 to December 2019, while for this study, only data covering the field study period was used.

2.7. Data processing

The questionnaires were coded into answer groups following pre- and post-determined answers using the statistical software SPSS v. 20 and subsequently imported into R for data visualisation, image creation, and analysis. Answer groups included, for example, knowledge about high catch seasons and factors associated with high or low catch seasons. Fish catch rates (based on CPUE), used as an index to estimate the relative abundance of a population, were obtained by standardising the weight of all fish landed at every landing site by the number of fishers involved in fishing (Harley et al., 2001) following:

$$Catch \quad rate \quad (CPUE) = \frac{Wt}{No}$$

where 'Wt' represents the wet weight of landed fish measured in kg, and 'No' is the number of fishers involved when fishing. Furthermore, since SSFs operate mostly inshore, and fishers perceive offshore as having less catch during high catch seasons, we zoned the SST data based on reef boundaries separating inshore and offshore areas to understand if the two environments differ in terms of catch rate. Data from the area between the coastline and reef boundary (within 15 km from the shoreline) were grouped as inshore, while data outside the reef boundary were grouped as offshore. SST observations recorded from May to October were categorised as SE monsoon data and those from November to April as NE monsoon data. These periods were used in the interviews and particularly when asking questions about fishers' perceptions of high catch seasons. Daily discharge data were aggregated into monthly averages to match fish catch data gathered from the Ministry of Livestock and Fisheries.

2.8. Analysis

A chi-square test of independence was used to assess fishers' perceptions of high catch season based on the frequency of the fishers' responses to seasons with a high catch (Table 2). Landing sites with similar characteristics based on the perceived seasonal catch variability were assessed using a dendrogram, which uses Euclidian distance to separate landing sites into clusters (Langfelder et al., 2008). Landing sites that showed high catch during the SE monsoon season were further analysed. The SE monsoon season group was tested for more environmental variables because the findings contrasted with normal catch patterns. We examined if rainfall intensity and/or water temperature affect catch patterns based on fishers' local ecological knowledge (Table 3). All statistical tests were performed with 95% confidence interval limits and statistical significance at an α level of 0.05.

To understand the contrasting catch patterns at the Nyamisati and Shangani sites compared to the other landing sites, we used high-resolution fish data (monthly landing data) from the Fisheries Department covering the same period as the catch rate data (2013–2014). Based on fishers' local ecological knowledge, the fisheries landings at Nyamisati and Shangani were generally dominated by prawn and tuna. To understand the fisheries dynamics, we assessed these two fisheries by comparing their catch rate patterns and the perceptions of the fishers. The fishers mentioned that the main factors causing high catches vary quite significantly as they are species-specific. At Nyamisati, we use river discharge (rainfall proxy) as a predictor variable for prawn catch and SST (a proxy for warmer and cooler periods) at Shangani for the tuna fishery; the fishers mentioned both factors to predict the high catch season (Table 3).

We explored factors that caused seasonal catch variability based on the fishers' responses to the interview questions of relevance (see Table 3). Catch rates at each landing site were visualised for the SE and NE monsoon seasons, and the seasonal differences in catch rates at each landing site were tested with a non-parametric Mann-Whitney U test. Chwaka and Kunduchi were excluded because of the small sample sizes (violating the assumptions) in these landing sites. The Spearman correlation test was used to test whether there was a significant association between river discharge and prawn catch at the Nyamisati landing site. We used the Mann-Whitney U test to examine whether there was a significant difference in SST between inshore and offshore waters during the NE and SE monsoon seasons. All analyses were done in R v. 4.03 and the ggplot2 package was used for mapping and plotting of data presented in the result section.

3. Results

3.1. Catch variability based on fishers' perceptions

We found a significant number of respondents (71.5%) claiming that their highest catches were obtained during the NE monsoon season (X^2 [7, n = 319] = 143.7, $p < 0.001$). Between 65% and 100% of the

Table 2
Summary of chi-square statistics for respondents claiming high catch of fish during either the NE or SE monsoon season at the selected landing sites. Counts refer to number of interviewees and statistics refer to chi-square statistic value. Significant values ($p < 0.05$) are shown in bold.

Site	Counts	Statistics	p-value
Deep sea	23	23	**< 0.05**
Bagamoyo	50	38.72	**< 0.05**
Kunduchi	37	29.43	**< 0.05**
Nyamisati	43	5.23	0.105
Somanga	38	2.63	**< 0.05**
Shangani	34	30.11	**< 0.05**
Kilindoni	45	18.68	**< 0.05**
Chwaka	49	27.94	**< 0.05**

Table 3
Factors responsible for the high fisheries catches at the different landing sites separated by season. Values presented are percentages of fishers out of a total of 319 interviewed fishers. NE = northeast monsoon season (May to October), SE = southeast monsoon season (November to April). Long rain season refers to periods of a high frequency of rainy days (usually occurring from March to May).

		Reasons for seasonal high catches		
Landing site	Season	Warmer period (NE)	Cooler period (SE)	Long rain season
Deep sea	NE	87.76	10.2	2.04
Bagamoyo	NE	82.22	17.78	-
Kunduchi	NE	97.06	2.94	-
Nyamisati	SE	36.84	-	63.16
Somanga	NE	67.44	32.56	-
Shangani	SE	5.41	94.59	-
Kilindoni	NE	94	6	-
Chwaka	NE	100	-	-

respondent fishers in Deep Sea, Bagamoyo, Kunduchi, Somanga, Kilindoni and Chwaka perceived that significantly higher catches are obtained during the NE monsoon season compared to the SE monsoon season ($p < 0.05$, Fig. 2). On the contrary, a high proportion of the respondent fishers in Nyamisati (63%, $p = 0.105$) and Shangani (95%, $p < 0.05$) perceived higher catches during the SE monsoon season compared to the NE monsoon season (Fig. 2).

Hierarchical cluster analyses of landing sites based on the fishers' responses to which of the two monsoon seasons that lead to the highest catches are visualised in Fig. 3. Spatial proximity appeared important during the NE monsoon season, where fishermen experienced similar catch rates within the two clusters, which correspond to the response patterns of catch rates in the northern (Bagamoyo, Deep Sea, Chwaka, Kunduchi, and Kilindoni) and southern regions (Somanga, Nyamisati, and Shangani) (Fig. 3a). In contrast, during the SE monsoon, Shangani and Nyamisati remained in one cluster, while Somanga was clustered together with Bagamoyo, Deep sea, Kilindoni and Kunduchi (Fig. 3b).

In general, the interviewed fishers (see Table 3) considered that SST and rainfall are the most influential factors for fish catches along coastal Tanzania. A substantial proportion (~67–100%) of the fishers at Deep sea, Bagamoyo, Kunduchi, Somanga, Kilindoni and Chwaka mentioned that the higher sea surface temperature during the warmer period (November to March) is the main factor causing the high catch rates during the NE monsoon season (Table 3). On the contrary, most (~95%) of the fishers at Shangani mentioned that the cooler conditions (occurring in May to September) cause the high catch rates in the SE monsoon season. Interestingly, a large proportion (~63%) of the fishers at Nyamisati perceived the extensive rainfall as the main factor contributing to high catch rates during the SE monsoon season (Table 3).

3.2. *Fish catch variability based on season and climate-related variables*

Catch rates at the studied landing sites varied during the field-survey period, with clear differences between the NE and SE monsoon seasons (Fig. 4). The median catch rates at Deep sea, Bagamoyo, Nyamisati, Kilindoni and Somanga were significantly higher during the NE monsoon season compared to the SE monsoon season ($p < 0.05$, Table 4), while the catch rate did not differ between monsoon seasons at Shangani (Table 4).

3.2.1. *Influence of rainfall (using river discharge as a proxy) on prawn catch at Nyamisati*

The discharge of the Rufiji River (near the Nyamisati landing site) varied over the studied seasons (Fig. 5). Based on river discharge data from the study period, in January, the river had a discharge of about 250 $m^{-3} s^{-1}$ (Fig. 5b). The river flow increased exponentially during the following months and reached a maximum discharge of 1690 $m^{-3} s^{-1}$ in May (Fig. 5b). Thereafter, there was a sharp decline in discharge from May to July, with relatively low river flow until November and a minor peak in December (Fig. 5b). There was a strong association between river discharge and total landing of prawn at Nyamisati (Fig. 5a). Water discharge was positively related to the total landing of prawn (Fig. 5a). For instance, the high total landings in April and May coincided with high discharge rates, while the lower landings in August, September and October coincided with low discharge rates (Fig. 5).

3.2.2. *Differences in tuna catch between monsoon seasons at Shangani*

The tuna catch rate at Shangani varied with season and was based on data from the 2013–2014 sampling period (Fig. 6). In comparison, the median catch rate of tuna was higher during the SE monsoon season compared to the NE monsoon season, although the observed seasonal difference was not significant (Fig. 6).

3.2.3. *Inshore and offshore waters of Shangani*

Seasonal SST differed slightly between inshore and offshore waters of the coast of Mtwara in southern Tanzania (Fig. 7). During the NE monsoon, the SST in the inshore waters was slightly higher than in offshore waters (Fig. 7a, Table 5), although no significant difference was found when comparing median values (Fig. 7a). During the SE monsoon, on the other hand, the median SST was clearly higher in the inshore waters compared to the offshore waters (Fig. 7b, Table 5).

4. Discussion

In Tanzania, most small-scale fisheries focus on shallow coastal habitats (mangroves, seagrass meadows and coral reefs), where the catches contribute more than 80% of the landed weight (Jiddawi and Öhman, 2002). Nevertheless, fisheries with little or no catch data pose a serious challenge to fisheries management and conservation. Especially in data-limited situations, fishers' local ecological knowledge (LEK) can help supplement information required for marine harvesting (Pilling et al., 2008; Reid et al., 2021; Tobisson et al., 1998). This study is one of a few that have compared the perceptions of fishers with detailed observations of a one-year fishery catch data sampling. The findings of this study and similar studies, such as Ban et al. (2017) and Daw et al. (2011), integrating community experience and science, show that a combination of fishers' LEK and scientific data can provide more relevant information on catch patterns than if scientific surveys are done independently. For example, this study's contrasting catch patterns observed at the Shangani and Nyamisati landing sites became apparent when the local knowledge was integrated with scientific knowledge. In the past, managers could not recognise such divergent catch patterns because the local variability and changes were hidden, which include information with greater precision than the regional statistics.

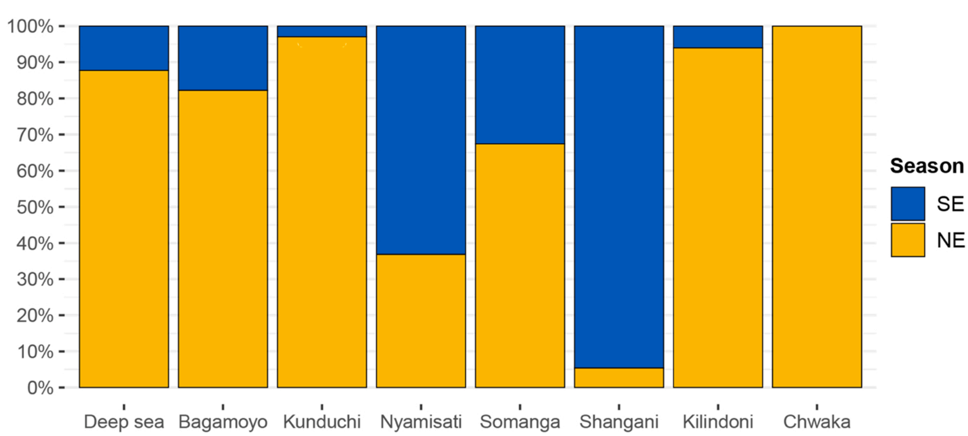

Fig. 2. Bar plot showing the proportion (%) of respondents claiming high catch of fish during either the NE or SE monsoon season at the selected landing sites. Statistics are presented in Table 2.

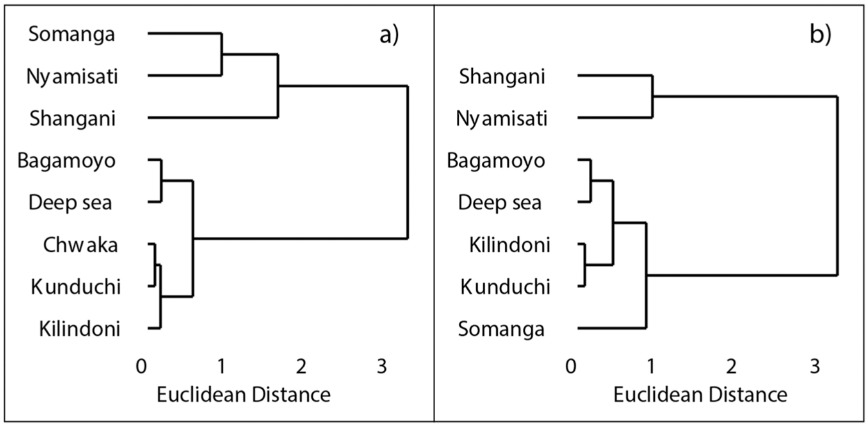

Fig. 3. Hierarchical clustering of landing sites based on fishers' perceptions of fish catch rate levels during (a) the northeast (NE) monsoon season (November to April), and (b) the southeast (SE) monsoon season (May to October).

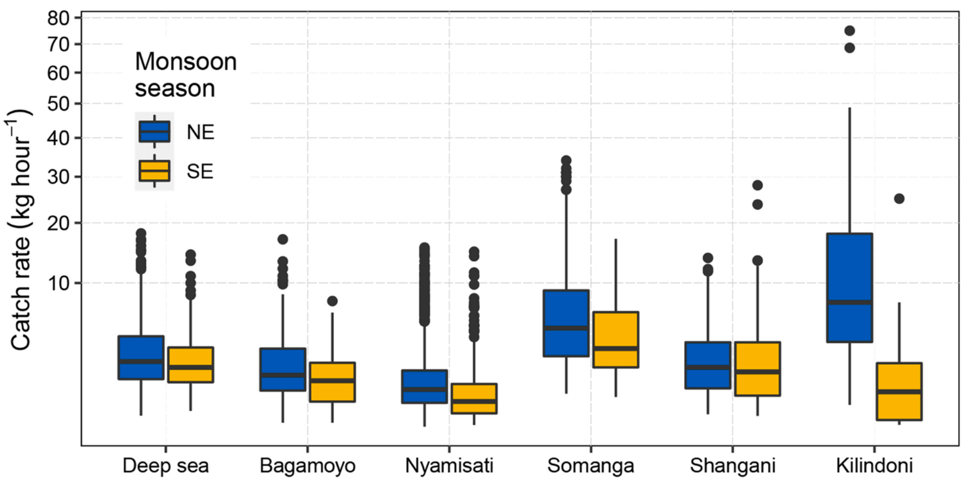

Fig. 4. Monthly catch per unit effort (CPUE, kg hr^{-1}) of the six fish landing sites spread over coastal Tanzania during the field survey in 2013–2014. The boxplot describes data symmetry, skewness and outliers.

Table 4
Multiple comparisons of catch rates between the northeast (NE) and southeast (SE) monsoon seasons for six fish landing sites spread over coastal Tanzania. Significant values ($p < 0.05$) are shown in bold.

Site	N	Catch rates (kg/hour)		Class limits		p-value
		NE	SE	lower	upper	
Deep sea	958	2.10	1.75	0.05	0.21	**< 0.05**
Bagamoyo	639	1.33	1.07	0.09	0.28	**< 0.05**
Nyamisati	2080	0.71	0.34	0.25	0.35	**< 0.05**
Somanga	1257	4.75	3.00	0.19	0.33	**< 0.05**
Shangani	501	1.75	1.50	0.01	0.20	0.08
Kilindoni	228	7.50	0.62	0.66	0.84	**< 0.05**

A large portion of the fishers interviewed in this study (71%) perceived that the NE monsoon season was the best fishing period. The finding agrees with previous studies, which have been based on total landed weights (McClanahan, 1988; Thoya and Daw, 2019) instead of CPUE as in this study. During the NE monsoon season, the warm weather, low wind speeds and slow ocean currents commonly provide better fishing operation conditions than during the SE monsoon's rough and turbulent waters (Thoya and Daw, 2019). Contrary to the general perception of fishers that catches are higher during the NE monsoon season than in the SE monsoon season, fishers at Nyamisati and Shangani had an opposite view. Many fishers of these two sites perceived the SE monsoon as a good fishing season with higher fish landings than in the NE monsoon season. In addition, the local fishers mentioned about the dominance of prawns at Nyamisati and tuna at Shangani. They also mentioned that the long rain season (March to May) is a driving factor for catches at Nyamisati and that sea surface temperature determines fish catches in Shangani. Furthermore, the fishers in Nyamisati mentioned that the mangrove forests extending over large areas of the Rufiji Delta are the reason for the dominance of prawns in the fishery catches. Past and present studies also designated Nyamisati as a mangrove forest-dominated area with high prawn biomass (Nyangoko et al., 2022; Silas, 2011; Wang et al., 2003). At Shangani, the local fishers mentioned that the deep water near the coastline provides a suitable environment for tuna fishing. Fisheries statistics also verified the dominance of prawns at Nyamisati and tuna at Shangani (MLF, 2018a).

The perceived low catch rates at Nyamisati and Shangani during the NE monsoon did not match catch records. While fishers of these two landing sites perceived the highest catches are obtained during the SE monsoon, data records depict the NE monsoon being the best season for fishing, which is similar to what was found by McClanahan (1988). But when using species-specific catch data (prawn data for Nyamisati and tuna data for Shangani), results matched the fishers' perceptions; both sites showed higher catches during the SE monsoon season compared to the NE monsoon season.

River discharge data, represented as rainfall, correlated well with prawn catch at Nyamisati, and the sea surface temperature gradient

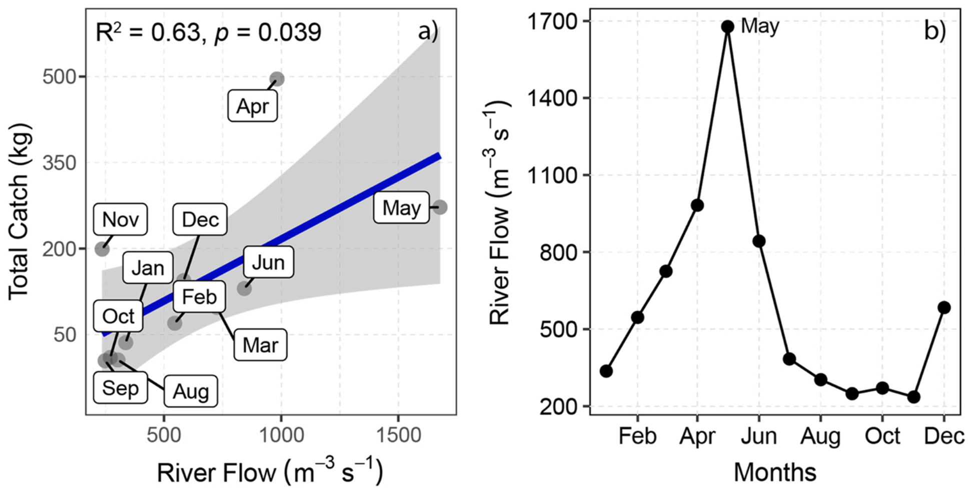

Fig. 5. Relationship between total landed weight and river discharge (a) and river flow rates across a year measured at Stiegler's Gorge on the Rufiji River near Nyamisati (b). The inset linear regression trend line in (a) shows a fish landing increase with river discharge. Data presented here cover the study period (June 2013 to April 2014) for Nyamisati.

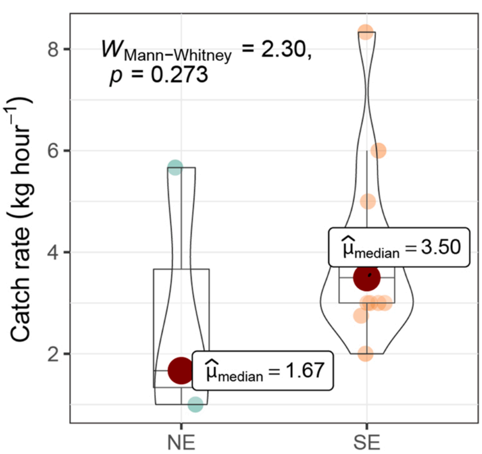

Fig. 6. Box plot showing differences in tuna catch rates between monsoon seasons in Shangani. Data
Source: Fisheries Department, Tanzania. NE = northeast monsoon season (May to October), SE = southeast monsoon season (November to April). Data presented here cover the study period (June 2013 to April 2014).

between offshore and inshore waters of Shangani explained tuna catch levels in different seasons. These recorded results also matched the fishers' perceptions in the respective sites. Variability of prawn catch with river discharge has previously not been shown in Tanzania, though some studies in the region show a similar association (da Silva, 1986; Gammelsrød, 1992; Sousa et al., 2006). Also, the linkage between tuna catch rate and the sea surface temperature gradient has never been studied along the East African coast. We speculate that the sea surface temperature during the cooler period of the SE monsoon season (from May through September) causes tuna to migrate inshore. Migration occurs since the inshore water is, on average, about two degrees Celcius warmer than the offshore water of Shangani, and tuna are known to migrate following favourable conditions (Takashi et al., 2000). In this study, only factors mentioned by fishers were considered, while other important factors, like the availability of prey items, which are also important (Polovina, 1996; Vanderlaan et al., 2014), were not considered. Therefore, it is important to focus research efforts on environmental and social factors that may affect species distribution in local areas to understand catch dynamics. This would be an important step towards effective resource management.

5. Conclusion and recommendations

This study integrates fishers' perceptions, catch effort data, annual fisheries statistics, and environmental data to bring a more complete scientific insight into the small-scale fisheries of Tanzania. The results show fishers are aware of how catch dynamics are linked to environmental fluctuations. Therefore, local ecological knowledge (LEK) can properly inform scientists and managers about high and low catch seasons or periods based on their experience, and relate factors associated with catch differences with high accuracy. This finding is essential for fisheries science; it shows that traditional knowledge could help understand fisheries variability. Thus, combining LEK and scientific knowledge in fisheries with limited data is essential for supporting research in achieving its targeted goals and aiding in achieving fisheries management goals. The LEK and fishers' perceptions can boost management practices by anticipating problems of implementation (Jones et al., 2014). It adds to precautionary approaches in data poor-fisheries, where comprehensive stock assessment studies are lacking or underway. Furthermore, considering the ocean's vastness, the extensiveness of the coastlines, the diversity of habitats in tropical seascapes, communities, and species, and the lack of human resources in marine science, fishers' LEK can be a powerful tool for generating scientific knowledge and should be considered in further scientific and policy-relevant research.

CRediT authorship contribution statement

Mathew O. Silas: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Masumbuko L. Semba**: Methodology, Formal analysis, Writing – review & editing. **Said S. Mgeleka**: Conceptualization, Methodology, Investigation, Writing – review & editing. **Lisa Van Well:** Writing – review & editing. **Hans W. Linderholm:** Conceptualization, Writing – review & editing, Supervision. **Martin Gullström:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

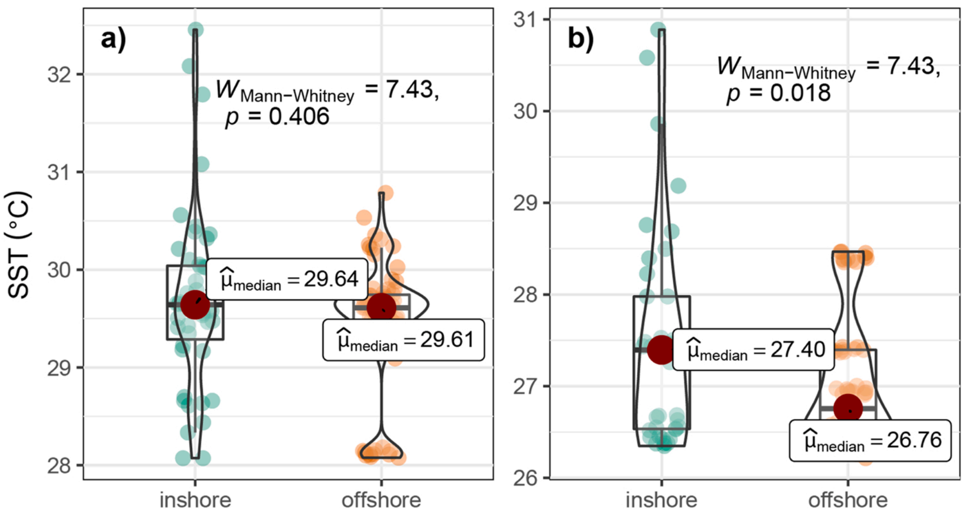

Fig. 7. Sea surface temperature (SST) in the inshore and offshore waters of the coast of Mtwara during (a) the northeast monsoon season, and (b) the southeast monsoon season. Data presented here cover the study period (June 2013 to April 2014).

Table 5
Summary of statistics of sea surface temperature (SST) in the inshore and offshore waters of Shangani during the northeast (NE) and southeast (SE) monsoon seasons. Data from the area between the coastline and reef boundary were grouped as inshore, and data outside the reef boundary (more than 15 km off the coastline) were considered offshore. Data presented here cover the study period (June 2013 to April 2014). No is the number of observations, Min and Max are minimum and maximum SST values in degrees Celsius (°C), and IQR (interquartile range) represents the middle half of the data where most data values lie.

Area	Season	No	Min	Max	IQR
Inshore	NE	47	28.07	32.46	0.75
Offshore	NE	66	28.07	30.79	0.32
Inshore	SE	40	26.34	30.89	1.44
Offshore	SE	66	26.21	28.47	0.92

Data Availability

Data will be made available on request.

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