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Ocean safaris or food: characterizing competitive interactions between recreational and artisanal billfish fisheries on the coast of Kenya

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ABSTRACT

Users of marine recreational and artisanal fisheries share a great interest in common resources, driving potential competitive interactions. In the Western Indian Ocean (WIO), limited information exists about these fisheries in particular for billfish species. The importance of billfish as a highly sought-after game fish species in recreational fishing, a source of food and income for artisanal fishers, and their ability to transverse various national jurisdictions as a shared resource make it necessary to evaluate sectoral interactions. Herein, we ask the question: what is the nature of these interactions in Kenyan waters?

We developed criteria for inferring competitive interactions based on time, space, and resource use and using billfish landings data collected through the creel survey, fishery-dependent sampling, and tagging. Results from tag recaptures show that both fishing sectors are capturing the same billfish resource, with a dominance of sailfish landings. We found no significant difference in the average landings between artisanal and recreational sectors, indicating equal demand for the billfish resource in terms of target species, geographic distribution, and seasonality. Therefore, our results suggest competitive interactions between the recreational and artisanal sectors, which have significant implications for management and socio-economic benefits for coastal communities.

1. Introduction

Fisheries resources are often exploited by multiple user groups, including large-scale industrial, artisanal, and recreational fishers, each with varying resource needs. Balancing the disparate demands for resources, objectives, and values of these different fishery users, which range from subsistence to recreation, requires the development of management decisions that address such issues (Girardin et al., 2015; Beitl, 2014; de Castro and Begossi, 1996). The nature of the limited resources and the spatial and temporal overlap between sectors may lead to competition between the different user groups (Kadagi et al., 2020; Babali et al., 2018; Barnes et al., 2016; Pawson et al., 2008). A failure to identify and characterize competition among fishery user groups can have negative implications on food and socio-economic security, result in cultural loss of fishing identity, and inhibit effective governance resulting in conflicts due to differences in resource use needs.

Competitive interactions among fishers are a common feature in fisheries. They can be inferred from the distribution of fishing vessels, fishing effort, catch rates, and target species (Barnes et al., 2016; Sys et al., 2016; Girardin et al., 2015). However, existing literature that seeks to characterize interactions among fishing sectors has primarily focused on specific features that cumulatively lead to competition rather than using set criteria to verify that these interactions are indeed competitive (Islam and Berkes, 2016; Dubois and Zografos, 2012; Bundy and Pauly, 2001; Kearney, 2001). One problem highlighted in several studies is that direct evidence for competitive interactions among fishers is complex and scarce (Gaichas et al., 2016; Marta et al., 2001). This is due to the general lack of empirical data and criteria to infer the occurrence of competition among fisheries user groups (Sys et al., 2016; Link and Auster, 2013; Rijnsdorp et al., 2000).

When defining competitive interactions between species in ecosystems, ecologists have commonly used three dimensions of resource use and partitioning which include: (i) the type of resource, (ii) the degree of overlap in the habitat of the species and (iii) the period of activity (Garcia and Vendel, 2016; Finke and Snyder, 2008; Bhat and Bhatta,

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2006; Berkes, 1984). For instance, if two species compete for prey, there is a likelihood that either exploitative or interference competition may force the weaker species to operate in a different space and activity time. In the case of fisheries users that target the same fish species, the limiting factors resulting in competitive interactions may include inadequate space in fishing locations, limited supply of the target species, and overlaps in periods of fishing. Fishers may be forced to search for different fishing locations, deploy a variety of fishing techniques and fish at various times to take advantage of the shared resources (Barnes et al., 2017). For example, in a study of competitive interactions between Dutch trawlers and Belgian beam trawlers in the North Sea, Sys et al. (2016) found that the landing rates for sole (an economically important species) were lower for Belgian beam trawlers as a result of increased fishing activity time by the Dutch trawler fleets. Similarly, in a tagging experiment to examine interactions between artisanal and industrial tuna fisheries in Papua New Guinea and the Solomon Islands, Leroy et al. (2016) found that industrial purse-seine fisheries may influence artisanal fisheries by decreasing the availability of local fish when they fished within similar fishing locations. While these examples underpin the significance of competitive interactions among user groups (e.g., reduced catches, lost employment days, and negative socio-economic outputs), identifying fishery features that indicate the existence of competitive interactions may improve the management of shared resources.

Much of our understanding of competitive interactions among user groups has focused mostly on competition between commercial fishing fleets, especially regarding resource access, and to a lesser extent between artisanal and recreational fisheries (Jariego et al., 2018; Dubois and Zografos, 2012; Branch et al., 2006; Ulrich et al., 2001). For example, competitive interactions have been documented between artisanal and industrial fisheries in West African countries such as Senegal (Belhabib et al., 2016, 2014) where the migrations of Senegalese artisanal fishers to meet their need for fish were strongly influenced by the increased effort from foreign fleets targeting the same resources. In Uruguay, Horta and Defeo (2012) found a strong interannual displacement of artisanal fishers by the commercial fleets for whitemouth croaker (Micropogonias furnieri). A common denominator exhibited by these examples is that target species, space, and time are among the key attributes for determining competitive interactions among user groups, especially for shared resources. Despite the growing realization of the importance of fisheries interactions, many gaps in knowledge remain globally, particularly in characterizing competitive interactions in recreational and artisanal fisheries.

On the other end of the spectrum, there is a growing school of thought that argues that recreational fisheries are less monitored and their environmental and socio-economic footprint is largely unknown (Freire et al., 2020; Hunt et al., 2019; Babali et al., 2018; McPhee et al., 2002). For example, Smith and Zeller (2013) found that recreational fisheries took most of the catches within the Bahamas waters, the majority of which were unreported, creating a heavy toll on fish stocks. Similarly, in Norway, it was estimated that recreational fisheries generated an average total catch of 13,400 tonnes from foreign fishing tourists, most of which was never reported (Hallenstvedt and Wulff, 2001). Vølstad et al. (2011) estimated the Norwegian re-construction of recreational catches at 3335 tonnes from tourist-fishing businesses and segments in 2009. Beyond the environmental footprint, which depends on the level of participation and the catch, recreational fisheries may also generate a conflict of use with other sectors such as the artisanal sector (Kadagi et al., 2020; Erisman et al., 2011).

Billfish, which comprise Istiophorid and Xiiphid species, are targeted by recreational, industrial, and artisanal fishing sectors (Ditton and Stoll, 2003; Kerstetter and Schratwieser, 2018). Despite their ecological and economic importance in various fisheries, limited studies on interactions between billfish fishery users have been conducted (Kadagi et al., 2020; Kopf et al., 2010; Brinson et al., 2009; Goodyear, 2007; Kearney, 2001). Billfish fisheries in Kenya and the Western Indian Ocean (WIO) region are no exception to the global deficit of knowledge about characteristics of interactions, particularly for recreational and artisanal fishing sectors that target these species. Recreational and artisanal fisheries, in general, are under-studied in the WIO, which adds on to the difficulty of addressing questions of the interactions between them.

Six species of billfish including sailfish (*Istiophorus platypterus*), blue marlin (*Makaira nigricans*), black marlin (*Makaira indica*), striped marlin (*Tetrapturus audax*), swordfish (*Xiphius gladius*), and the short-billed spearfish (*Tetrapturus angustirostiris*) are found in the Kenyan waters (Harris et al., 2013; Kadagi et al., 2011). Billfish species, especially marlins, are highly sought after in recreational fisheries (also termed as game fishing or sport fishing), which has contributed to Kenya's prominence on the world map as a 'hotspot' billfishing destinations where an angler is likely to catch a 'fantasy slam' (that is five different billfish), with the first such record achieved in 2005 and two other fantasy slams in 2009. Here, we use the term "recreational billfish fishery" to refer to private and charter sporting operations that use hook and line as the main gear (Pepperell et al., 2017). Alternatively, billfish species such as sailfish are landed in artisanal fisheries as a source of livelihoods (Kadagi et al., 2020). Artisanal fisheries constitute around 80% of the fishing fleets along the Kenyan coast, with about 13,000 fishers (GoK, 2016). Artisanal fishers use a range of fishing gears, which vary from traditional to modern, operated from small to medium-sized fishing crafts/vessels (Omukoto et al., 2018; Fulanda et al., 2011).

Given the importance of billfish among the recreational and artisanal sectors, two knowledge gaps motivate this study. First, there are generally limited studies on billfish in Kenya and the wider WIO region. Second, there are no studies that have focused on defining criteria for evaluating interactions between recreational and artisanal billfish fisheries in Kenya and the WIO. Therefore, this study aims to develop a set of criteria for inferring and classifying competitive interactions in recreational and artisanal billfish fisheries in the WIO region to address challenges that may arise from multiple resource use needs.

Using data from Kenyan recreational and artisanal billfish fisheries, we employ the three dimensions of resource use and partitioning to characterize competitive interactions, including (i) the type of resource, (ii) the degree of overlap in the species habitat, and (iii) the period of activity. Based on these three dimensions, three primary questions guided the characterization of these interactions. Firstly, do both kinds of fisheries users target the same billfish species? Secondly, are these two fisheries overlapping in the areas of fishing? Thirdly, how does the period of fishing activity in relation to seasonality changes influence interactions in these two fisheries? Thus, the specific objectives of this study were to: (i) evaluate the composition of billfish landings in the two fisheries, (ii) examine spatial and temporal overlap between two fisheries in fishing locations, (iii) assess the overlaps between the two fisheries in relation to seasonal changes, gears and target species, and (iv) identify the factors influencing the differences in billfish landings between the two fisheries.

Characterizing fisheries interactions across space and time is pivotal in several ways. Firstly, this information is pertinent in developing management strategies, especially for shared fishery resources such as billfish. Secondly, understanding the diversity of interactions is useful in determining the socio-economic importance of billfish fisheries. Thirdly, exploring the multi-level interactions is essential in developing ecosystem-based management strategies. Our study provides a starting point for understanding competitive interactions between recreational and artisanal fisheries in the context of billfish species. Thus, their transboundary nature makes a case for consideration of fisheries interactions in the regional management of billfish populations.

2. Materials and methods

This research relied on four sources of primary and secondary data to describe competitive interactions between recreational and artisanal billfish fisheries. These data are described as follows:

2.1. Primary data

2.1.1. Artisanal intercept data

Trained enumerators collected artisanal landings data through the Kenya Coastal Development Project[1] (KCDP), from June 2013 to December 2016. This study focused on the fish landings locations of Mtwapa, Takaungu, Mranani, and Uyombo that are in Kilifi County along the Kenya coast (Fig. 1). Data included the date of fishing, fisher county of origin, gear (type and number), vessel/craft used, location of catch, departure time, arrival time, taxa type, weight, and number. These data were collected over ten days each month, with sampling days corresponding to the two seasons, the northeast monsoon (NEM), which occurs between October and March, and the southeast monsoon (SEM), which runs from April to September (McClanahan, 1988a; Schott and McCreary, 2009). The SEM and NEM have been known to correlate with the intensity of fishing activities along the Kenya coast (Munga et al., 2013). The calm seas during the NEM result in increased fishing activity, whereas the characteristics of rough seas in the SEM decreases fishing activity.

Additional data, such as information on non-zero/positive landings, types of fishing craft/vessel and gears used, fishing sites, and season, was collected for Kilifi County. This county has a high proportion of artisanal fisheries that catch a variety of species, including small, medium, and large pelagics. Specifically, Kilifi County has sixty-seven fish landing sites-the highest number of fish landing locations, as revealed by the biannual frame surveys last conducted in 2016. These surveys collate information on the fishing effort distribution, particularly for artisanal gillnet and longline gears (GoK, 2016). This information was recorded simultaneously across all sites on the selected sampling dates. Global Positioning System (GPS) coordinates for artisanal fishing locations were also collected during the survey. Each vessel heading out to sea was allocated an observer, or in some cases, the fishers were provided with a GPS device to record their fishing grounds.

2.1.2. Artisanal and recreational creel survey data

Creel surveys, which involved interviews with fishers, were conducted from May 2016 to April 2017 to collect landings and effort data (number of fishing days and boats) for the billfish fishery. The surveys focused on two fisher groups (recreational and artisanal) that caught billfish in Watamu and Malindi (Fig. 1). Site selection was based on the researchers' prior knowledge that most sportfishing tournaments and competitions took place in Watamu and Malindi. Most of the recreational charter operators were organized into sportfishing clubs that are members of the Kenya Association of Sea Anglers (KASA), an umbrella body representing both private and charter sportfishing skippers, and private boat owners. Specifically, Malindi has the oldest sportfishing club in East Africa, the Malindi Sea Fishing Club, which was established in the 1950s, and thus it was a source of historical data.

Malindi and Watamu are also home to a multi-species and multi-gear artisanal fishery with several landing sites. Local communities rely on fishery resources for their food and livelihoods. The study sites were sampled over ten to sixteen days per month to record various information. These included billfish species landings, the reported mean weight (measured in kilograms), type and size of fishing craft/vessel, fishing grounds, season, and estimated distance traveled in nautical miles from shore to fishing grounds.

2.2. Secondary data

2.2.1. Recreational fisheries tagging and recapture data

Secondary data for recreational fisheries were obtained from the African Billfish Foundation (ABF) tagging database. The Foundation has overseen the tagging of billfish and other gamefish species in the WIO since the mid-1980s through its network of recreational fishing tourists/anglers, boat captains, and crews. The Kenyan recreational fishery is designated as mostly catch and release for billfish species while other gamefish species such as the giant trevally, kingfish, and rainbow runner are landed. Based on the ecological theory, a released fish becomes the subject of competition. On the one hand, recreational fishers practice catch and release as a conservation measure with the hope of catching it again. Still, the same fish is likely to be caught for food by artisanal fishers who do not practice catch and release.

Billfish tagging data were available from 2013 to 2016, from the three main sportfishing centers of Malindi, Watamu, and Mnarani located in Kilifi County (Fig. 1). The data included species landed, type of vessel, main gear used, fishing grounds, date fished. Additional data from the recreational tagging database included GPS coordinates for some of the identified fishing grounds and locations where billfish were caught, tagged, and released.

Recapture data for billfish species were obtained through ABF from 1990 to 2016, consisting of fish that were previously tagged and recaught. These data included the species, gear used, and type of fishery involved in the recapture, release, and landing of the billfish.

2.3. Data analyses

We used a methodical framework based on how ecologists infer competitive interactions between different species based on three dimensions of resource use and partitioning (Garcia and Vendel, 2016; Finke and Snyder, 2008; de Castro and Begossi, 1996; Berkes, 1984). These dimensions included the type of resource, degree of overlap in the habitat of the species, and period of activity. In this study, the type of resource refers to the composition of billfish species landings. The species' habitat refers to fishing grounds, and the period of activity was based on seasonal changes.

2.3.1. Composition of billfish landings in recreational and artisanal fisheries

The proportion of billfish landings for the two user groups was analyzed from artisanal intercept and recreational fisheries tagging data. We also calculated proportions of recaptured billfish species from the recreational tag-recapture data. The proportions of recaptured species were used as an indicator of competitive interactions, especially when considering that recreational fishers predominantly practiced catch, tag, and release, while artisanal fishers landed the billfish. Thus, understanding the magnitude of recapture proportions in the two user groups would indicate interactions between the fisheries.

2.3.2. Co-occurrence of species landed in recreational and artisanal fisheries

The co-occurrence of species landed was used as an indicator of competitive interactions. The total number of the giant trevally and sailfish, the two most landed species were extracted from the artisanal intercept and recreational tagging data to calculate species co-occurrence. Most species in the artisanal data set lacked individual weights, given that weights were aggregated in the initial reporting. Therefore, to obtain a total count for sailfish and giant trevally from artisanal fisheries, the analysis was restricted to the data with recorded weights of individual fish. This was done to minimize variability within the data, and to avoid the problem of standardizing landings for sailfish and giant trevally across different vessels and gear types and double counting for the species. The recreational tagging data were different in that each tagged individual was recorded separately and not as aggregated weight.

Co-occurrence in the fish landings between recreational and artisanal fishers was determined using the Williamson spatial overlap index (SO_{ij}) described in (Williamson, 1993), in which the overlap index SO_{ij} was expressed as follows:

[1] A World Bank funded initiative to promote environmentally sustainable management of Kenya's coastal and marine resources.

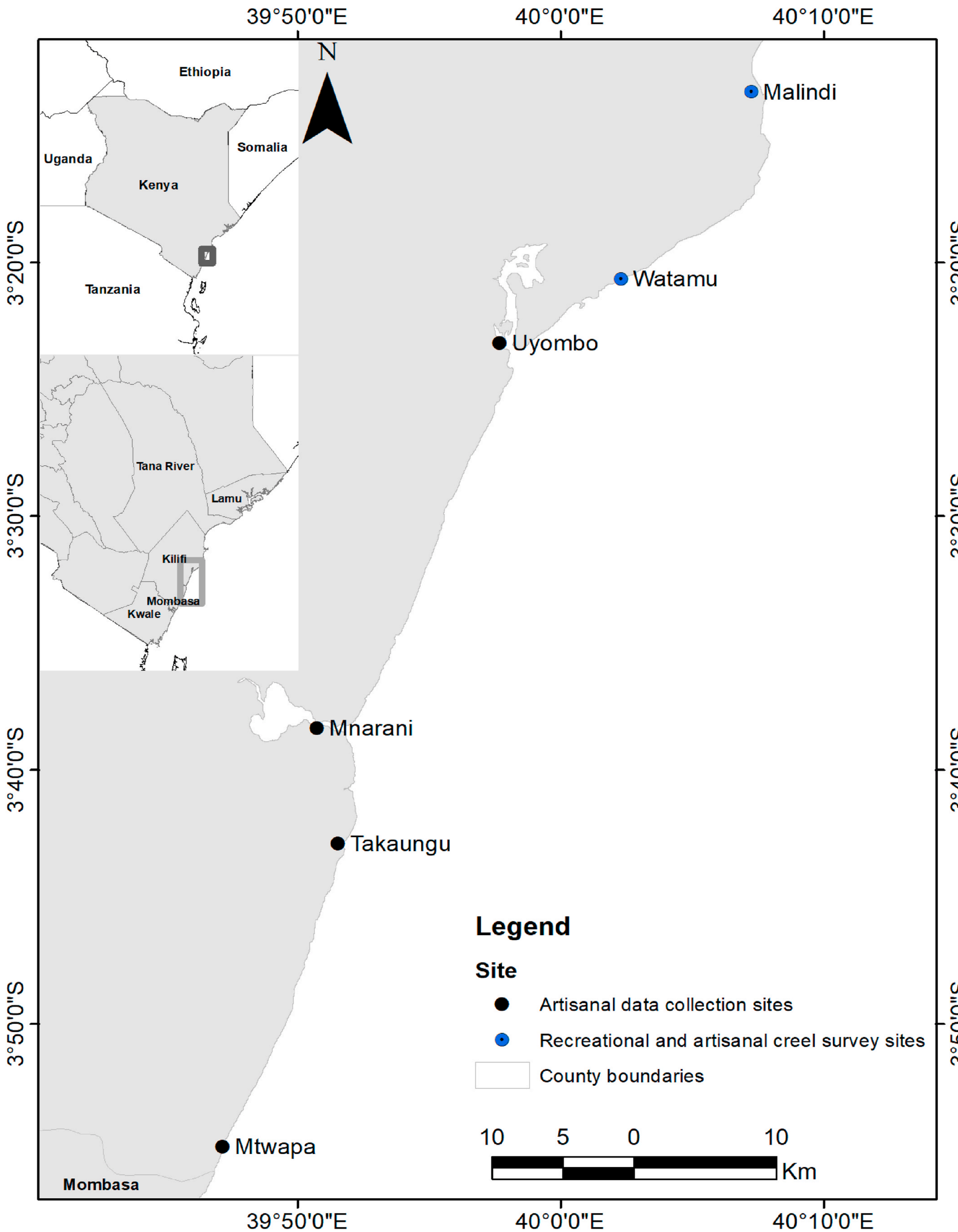

Fig. 1. Map showing the location of Kenya, with a close-up of Kilifi County, one of the five counties located along the Kenya coastline, with main sampling sites: Mtwapa, Takaungu, Mranani and Uyombo for artisanal intercept data and Malindi and Watamu for recreational and artisanal creel surveys.

$$SO_{ij} = \frac{\sum_z (N_{iz} N_{jz}) m}{\sum_z (N_{iz}) . \sum_z (N_{jz})} \quad (1)$$

The equation above was modified where z represents the reported fishing ground, m is the total number of landings of sailfish and giant trevally. These two species were denoted as i and j, where N_i is the total number of species of i and N_j is the total number of species j landed. Reported fishing ground (z) were obtained from the recreational tagging and artisanal intercept data. Given recreational and artisanal fishers reported grounds where the fish were caught, the study assumed that the fishing grounds represented the sample sites. Therefore, fishing grounds were standardized by only including locations of capture for sailfish and giant trevally in both fisheries.

A spatial overlap index (SOI) provides an indicator of the degree of overlap of sailfish and giant trevally based on the reported fishing locations (z). SOI predicts the overlap of fishing gear and species in each fishing ground based on their distribution and density. An SOI of 1 represents uniform distribution of gear and species, an SOI >1 represents a greater than expected gear-species overlap, and an SOI <1 represents a lower than expected gear-species overlap.

2.3.3. Area of operation and overlap between recreational and artisanal Fishers in fishing grounds

The percentage overlap of recreational and artisanal billfish fishers in the fishing grounds was used as a metric of competitive interaction. This was important, particularly in a scenario where fishers targeted similar species in the same locations.

2.3.4. Factors influencing billfish landings between recreational and artisanal fisheries

The artisanal and recreational creel survey data were used in multiple linear regressions (Eq (2)) to test the effects of season, distance traveled for fishing, boat size, and fishery type on billfish landings. The mean weight of billfish landed was set as the response variable while season, boat size, distance fished, and fishery type were predictor variables. The model for the relationship between mean landings of billfish per fisher, denoted as Y and model coefficients were therefore given as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_k X_k + \varepsilon \quad (2)$$

where Y is the response variable (average weight of billfish landings), X_k are the explanatory variables (season, distance traveled for fishing, size of boat and fishery type), β_0 is the intercept, β_k are the coefficients that were estimated by maximum likelihood, and ε represents the error structure. The variables were fitted as fixed effects by using the R statistical package, version 3.5.1 (R Core Team, 2017). The regression model combinations of fixed variables were compared for their fit to the data with the Akaike's Information Criterion (AICc) values based on maximum likelihood estimation (Zuur et al., 2009).

Several hypotheses to evaluate the influence of predictor variables on the billfish landings were tested. First, the season would have a substantial effect on billfish landings due to the change in average seastate. Second, the fishery type would impact the billfish landings due to different valuations of the catch by fishery sectors. Third, distance traveled for fishing would have no impact on the billfish landings given that the recreational and artisanal fishers caught billfish in similar fishing locations. Fourth, the size of the fishing vessel was postulated to have no impact on billfish landings due to the variations in fishing gears, especially from the artisanal fisheries. Fifth, the interaction effect of season and fishery type was hypothesized to have a strong impact on the billfish landings. The strong impact would be due to a decrease in the number of fishers during the SEM season and variation in gears, especially in artisanal fisheries. The NEM season also coincides with most recreational fishing competitions and tournaments. Therefore, season and fishery types were expected to have a strong influence on billfish landings.

3. Results

3.1. Competitive interactions based on the type of resource

Findings showed heterogeneity in artisanal landings of large and medium pelagic species belonging to the eight major families between 2013 and 2016 (Fig. 2). Out of the eight families, Scombridae constituted the most species landed while billfish accounted for 3%. Both recreational and artisanal fisheries landed sailfish, blue marlin, black marlin, and swordfish. Striped marlin and spearfish were only recorded in recreational fisheries (Table 1). Sailfish dominated most billfish landings in numbers with 63.2% and 48.9% in artisanal and recreational vessels, respectively. About 24% of landings in artisanal fisheries were categorized as "billfish not elsewhere identified" abbreviated as Billfish NEI.

Average landings (in weight) per day for the period 2013–2016 showed differences between artisanal and recreational fisheries. Specifically, the recreational fisheries had higher average landings per day compared to artisanal fisheries during 2014, 2015, and 2016 (Fig. 3). In addition, the average weight of billfish ranged between 39±31 kg and 55±52 kg in artisanal and recreational fishers.

The number of recaptured billfish by method of capture showed mixing and interaction between recreational and artisanal fisheries (Fig. 4). Sailfish constituted 94% of the total billfish recaptures. Eighty six percent of sailfish recaptures were recorded in artisanal gears while 10% were recaught by recreational rod and line. Black marlin were evenly distributed between artisanal (37%) and recreational fisheries (48%) A total of 87% of billfish tagged by recreational fishers were recaught by artisanal fishers.

3.2. Competitive interactions based on period of fishing activity

The combined proportion of billfish landings in artisanal and recreational fisheries were high during the NEM (88.8%) compared to the SEM (16.2%). Specifically, the proportion of billfish caught recreational fishers was 90% in the NEM and 10% in the SEM. Artisanal fishers landed 66% in the NEM and 34% in the SEM. Artisanal fishers showed diversification in gear use during NEM and SEM season (Fig. 5). However, billfish species were not caught in cast nets and reef nets in the NEM, whereas during the SEM, they were absent in the longline and ringnet. The recreational fishers predominantly fished using rod and reel or trolling in both seasons, recording a 50% proportion of landings in each of the gears.

Recreational billfishing occurred for an average of one month during the SEM season (July–August) and 6 months during NEM. Artisanal billfishing was recorded throughout the year.

3.3. Competitive interactions based on fishing grounds

Co-occurrence of sailfish and giant trevally was found between the recreational and artisanal gears during the NEM. Sailfish had a slightly higher SO_{ij} of 0.52 compared to giant trevally, which had an SO_{ij} of 0.48. Overall, most fishers in both sectors operated in the same fishing grounds (Fig. 6a). Specifically, the spatial overlap between artisanal and recreational fishers was 84% in the recreational fishing areas 32% artisanal fishing areas (Fig. 6b).

3.4. Factors influencing billfish landings between recreational and artisanal fisheries

Model 1, which had the smallest AICc, best described the influence of the predictor variables on billfish landings. (Table 2). This model included the effect of fishery type, seasonality, boat size, and distance traveled and interactions between fishery type and season. The results show that the interaction effect of season and fisheries had a strong influence on the total landings ($p = 2.20e^{-16}$) (see Table 3).

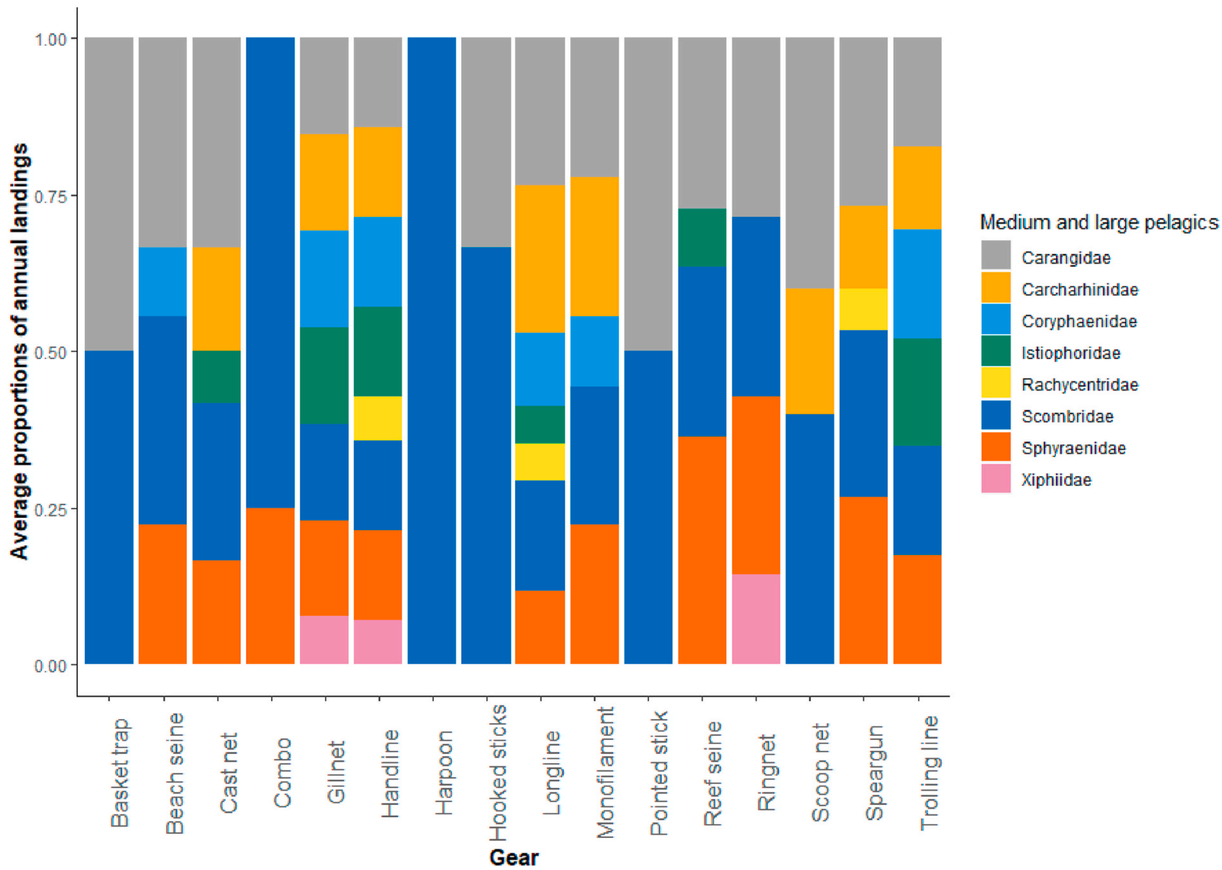

Fig. 2. Proportions of medium and large pelagic fish landings by artisanal fishing gears and family type in Kilifi County, Kenya, for the period between 2013 and 2016.

Table 1
A summary of the percentage distribution of total billfish landings by species (numbers of fish) in recreational and artisanal fisheries from 2013 to 2016 in Kilifi County.

Species	Artisanal fisheries	Recreational fisheries
Sailfish	63%	49%
Blue marlin	1%	22%
Black marlin	8%	9%
Broadbill swordfish	4%	3%
Billfish NEI	24%	0
Spearfish	0	0.1%
Striped marlin	0	19%

The model returned no significant results for the variables SEM, distance traveled, and boat size at $P > 0.05$ (Table 4). The recreational fisheries have a significant negative impact on average billfish landings during SEM season ($P < 0.05$.)

4. Discussion

This study characterized competitive interactions in recreational and artisanal fisheries with specific reference to billfish species in Kenyan waters. We also developed criteria for inferring competitive interactions based on time, space, and resource use. Our findings indicated that recreational and artisanal fishers targeted the same billfish species, used the same fishing grounds, and overlapped based on the period of fishing activity. Results supported the hypothesis that the interaction between seasonality and fishery type had a significant influence on billfish landings, whereas boat size, distance fished, and season had none. Our study provides evidence of interactions between artisanal and recreational billfish fisheries based on the dimension of resource use and partitioning (i.e., type of resource, habitat, and period of fishing activity). Understanding competitive interactions among fisheries user groups is essential in ensuring the social, cultural and economic security, development of sustainable management strategies and addressing conflicts due to differences in resource use needs (Leroy et al., 2016; Sys et al., 2016; Ulrich et al., 2001).

Competition for the same fish species may cause diversification in fishing methods and gear use. For instance, the variety of gears increased the chances of overlap in target species between the two fisher groups. Because artisanal fisheries target multiple species, gear diversification can increase the chances of catching new species, especially where there is a decline in the formerly targeted species (Selgrath et al., 2018; Davies et al., 2009; Lavides et al., 2016; McClanahan et al., 2008b). In the case of shared resources such as billfish, this then increases the competitive ability, as shown by the proportion of billfish landings and recaptures. Further, recreational fishers maintain the same gear while artisanal fishers mostly change their fishing strategies and gears according to seasonal changes throughout a given fishing year. Kadagi et al. (2020) observed that billfish are opportunistically caught species in multi-gear small-scale fisheries, which align with our findings that billfish are caught among other medium and large and medium pelagic fish species. Other studies have also reported the multi-gear and multi-species nature of artisanal fisheries in the WIO (Chande et al., 2019; Mangi et al., 2007; Tuda et al., 2016). Specifically, the high proportion of sailfish in artisanal fisheries might be due to sailfish occurring in the inshore waters compared to the other billfish species (Kadagi et al., 2020; Williams, 1970; Howard and Starck, 1975). However, the implications of multiple gears on billfish species are less studied in the WIO.

An analysis of the fisheries in the WIO, in general, has shown that

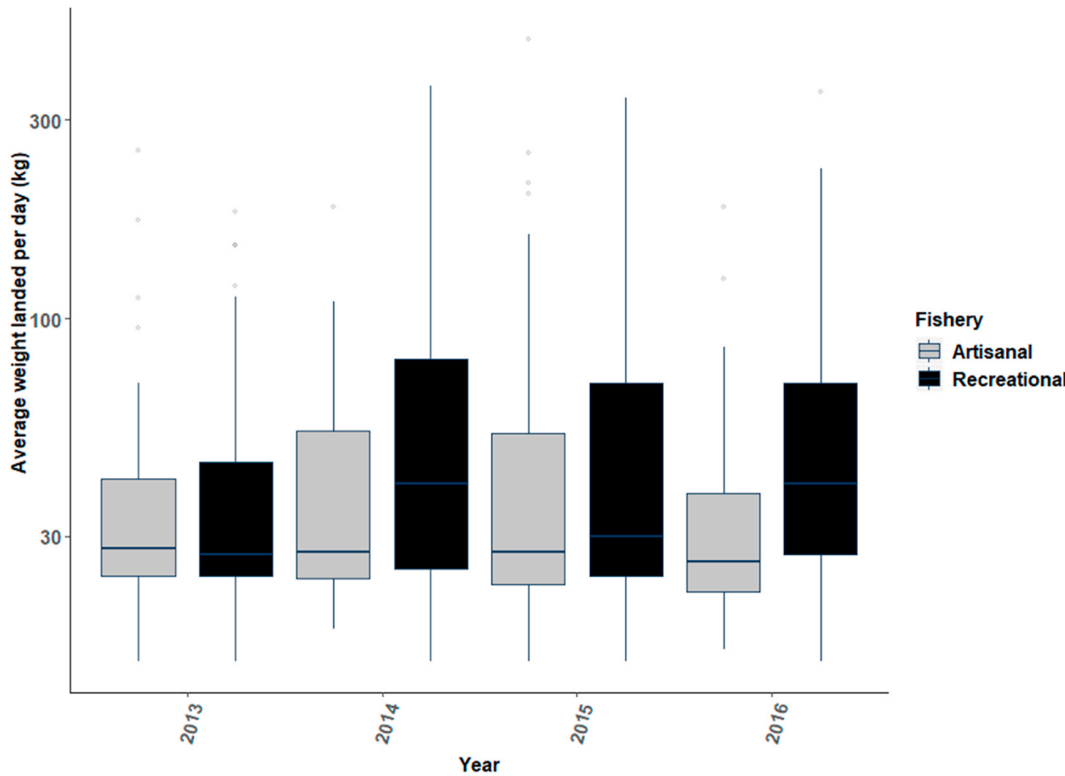

Fig. 3. Boxplots showing the distribution of the average weight of billfish landings (kilograms) per day in recreational and artisanal fisheries from 2013 to 2016 in Kilifi County, Kenya.

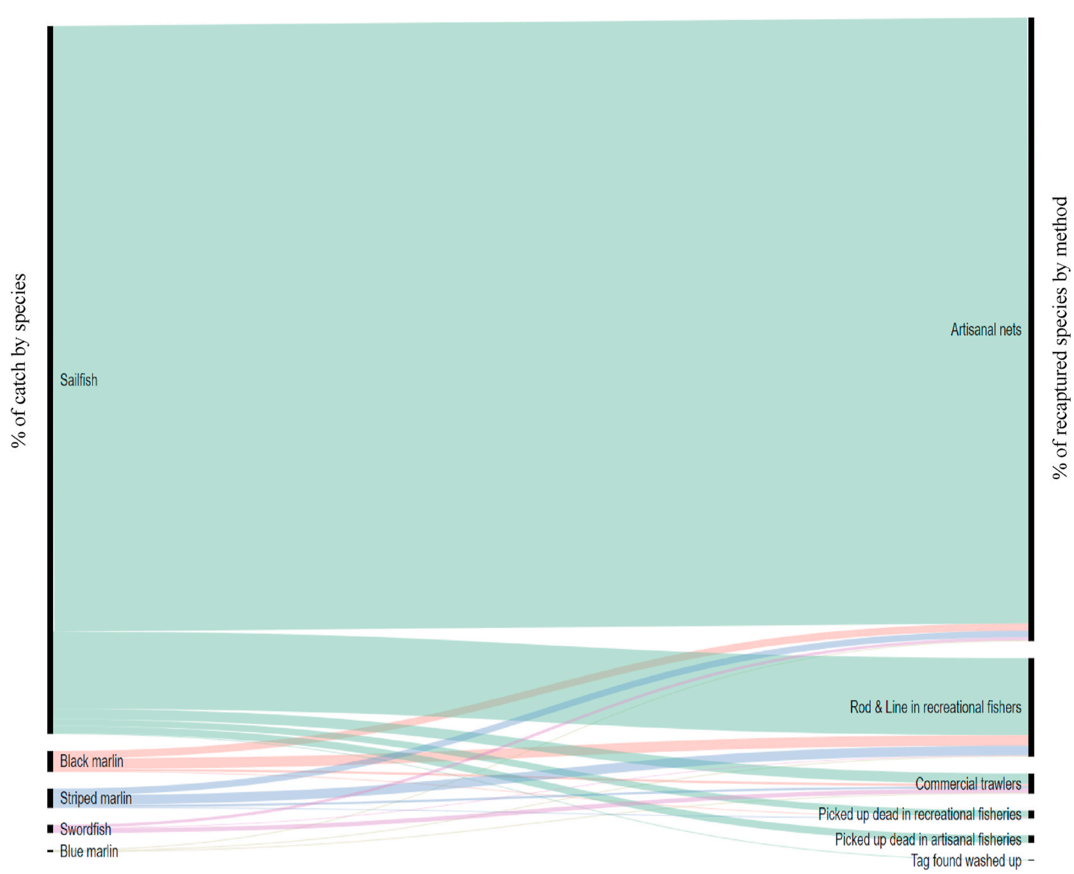

Fig. 4. Distribution of recaptured fisheries across sectors, 1990–2016 in Kenya.

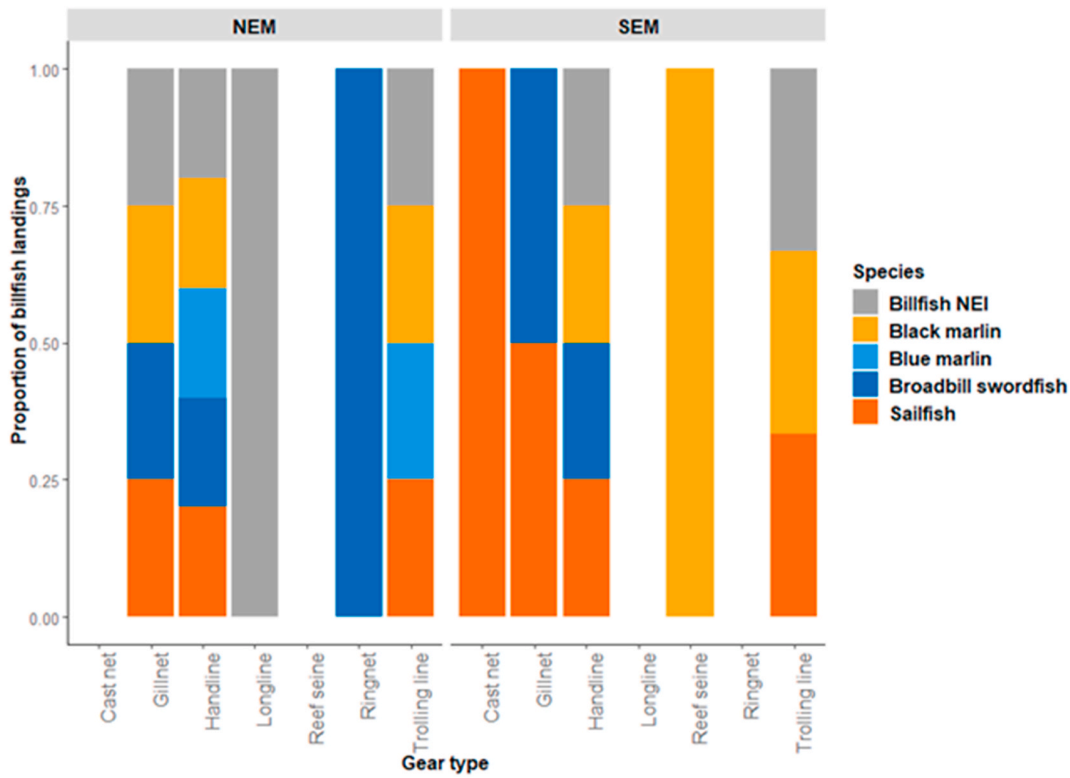

Fig. 5. Proportions of total billfish landings by numbers from artisanal gears between 2013 and 2016 in Kilifi County, Kenya.

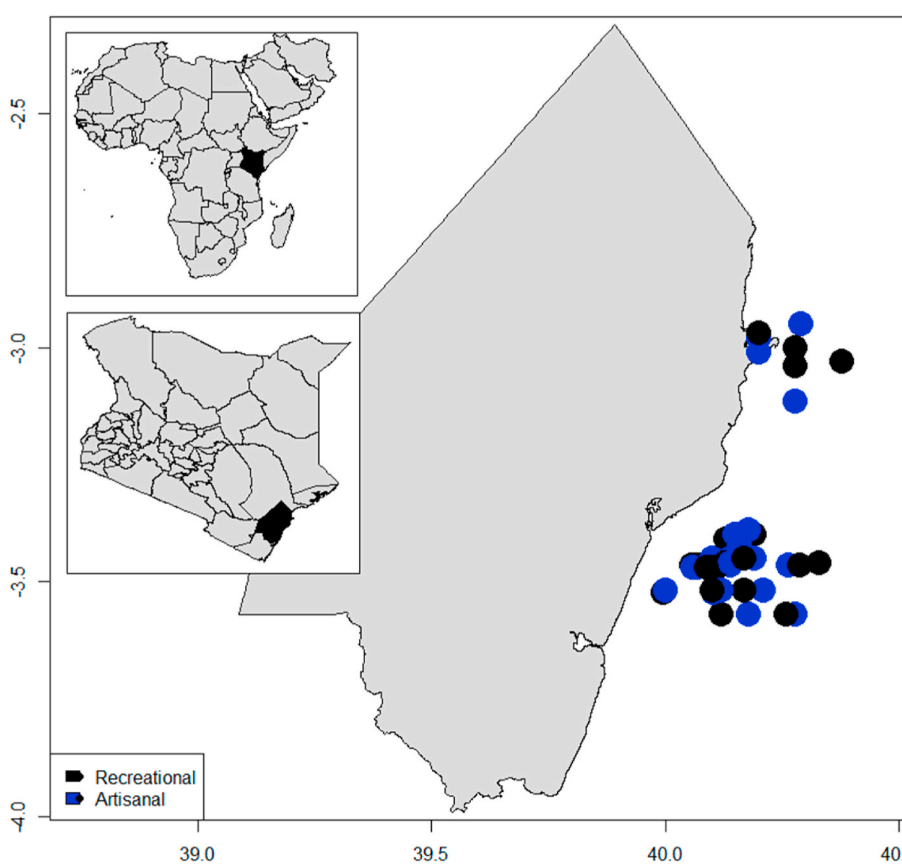

Fig. 6 (a). Spatial distribution of fishing grounds used by recreational fishers marked in black and artisanal billfish fishers in blue. Data source: tagging and interview data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

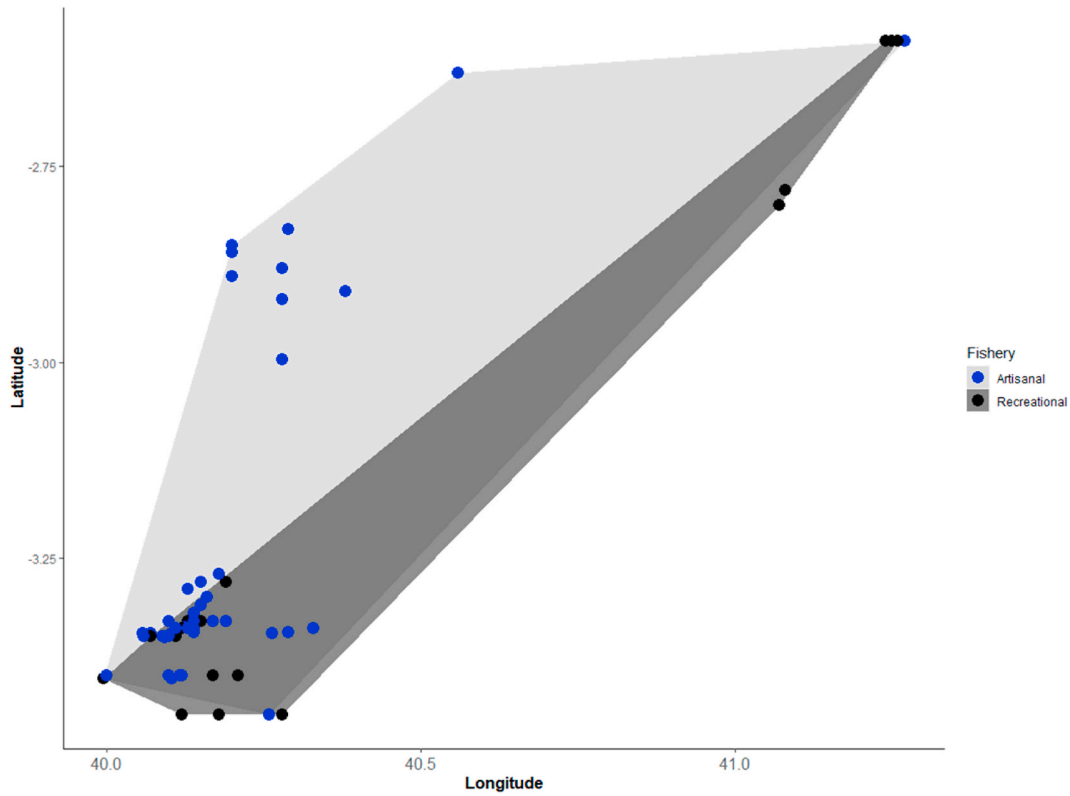

Fig. 6 (b). Areas of operation and distribution of recreational and artisanal fishers targeting billfish in reported fishing locations in Kilifi County for the period between 2013 and 2016. The light grey polygon represents the areas of fishing operation by artisanal fishers. The dark grey polygon represents areas of fishing operations for recreational fishers. The blue dots represent the distribution of artisanal fishing vessels, while recreational vessels are indicated by the black dots. Data source: tagging and interview data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Akaike Information Criteria (AIC) values for each stage of the stepwise model selection process, with fishery type (F), boat size (B), distance traveled from the shore (D) and the season (S) as candidate models.

Model Name	Model variables	K	AICc	Delta_AICc	AICcWt	LL	Cum.Wt
Model 1	F + S + D + B + F*S	7	871.8461	0	1	−428.73	1
Model 2	F + S	4	952.1811	80.33503	$3.59e^{-18}$	−472.022	1
Model 3	F + S + D	5	953.3868	81.54074	$1.97e^{-18}$	−471.591	1
Model 4	F + S + D + B	6	953.5179	81.67183	$1.84e^{-18}$	−470.615	1
Model 5	F + B + D	3	965.2447	93.39858	$5.23e^{-21}$	−479.582	1

Table 3
Coefficients from the best model fitted to average billfish landings of recreational and artisanal.

Variable	Coefficients	Standard error	P-value
Intercept	4.461	0.19	$2.0e^{-16}$ ***
Recreational fisheries	0.412	0.17	0.02 **
SEM	0.321	0.18	0.08
Distance traveled (nm)	−0.012	0.03	0.67
Boat size (ft)	−0.014	0.008	0.09
Recreational Fisheries in SEM	−2.525	0.25	$2.0e^{-16}$ ***

artisanal fishers constitute the highest proportion compared to other user groups (Everett et al., 2015; GoK, 2016; Temple et al., 2018). One striking observation in this study is the high proportion of billfish landings in artisanal fisheries, a species predominantly sought by recreational fishers. The shift in the magnitude of interaction based on the type of resource could introduce competition between artisanal and recreational fisheries (Kadagi et al., 2020). Competitive interactions occur because the two fisheries harvested the same billfish species, except striped marlin and spearfish, primarily present in recreational fisheries. One plausible explanation for the overlap in target species may be the use of versatile multi-gears by artisanal fishers, which are indiscriminate and more likely to catch a variety of species compared to the hook and line methods predominantly used by recreational fishers. Drift gillnets may be set out in the designated areas and left to soak for some time during which a variety of fish swim or drift in the tides and currents into the nets. Artisanal fishers may use surface, midwater, and bottom gillnets, which increases the chances of catching an array of billfish species. These findings are supported by previous reports showing that the high diversity of species found is due to the use of non-selective gears (Tuda et al., 2016; Davies et al., 2009).

The numbers of recaptured billfish provide a direct measure of competitive interactions between the fishery user groups based on the proportions of tagged and recaptured billfish. Recreational fishers tagged and released about 90% of billfish, while artisanal fishers recaptured about 87% of tagged billfish in nets. Sailfish comprised most of the recaptures (Kadagi et al., 2011). There are several explanations for the direct competitive interaction for sailfish. First, the interaction could be due to the occurrence of sailfish in nearshore habitats. Leroy et al. (2016) noted competitive interactions between industrial purse seine and artisanal fleets, especially for skipjack and yellowfin tuna, due to their longer residence times in nearshore waters. Hence, the residency of sailfish in nearshore waters increases their proximity to artisanal fishing grounds locations and the probability of recapture in artisanal fishing gears. Second, the interaction could be attributed to the numbers of sailfish tagged historically compared to other billfish species. Based on ABF tagging data, sailfish are about 83% of the total billfish that have been tagged and released in the over 20 years of its operation (Harris et al., 2013; Kadagi et al., 2011), and thus increases the chances of sailfish being the majority of the billfish species caught. Third, the high number of recaptures for sailfish in artisanal fisheries could be due to the relatively high levels of fishing effort throughout the year compared to recreational fisheries. Fourth, the high number of recaptures in artisanal nets may be due to increased localized artisanal fishing effort compared to recreational fishers.

Findings show that season affects the occurrence and intensity of competition between recreational and artisanal fishers. The high fishing effort in terms of the number of months fished for both fisheries during NEM provides probable evidence for competitive interactions based on period of fishing activity. These interactions may be less pronounced in the SEM because most charter sportfishing operations are closed. Our findings regarding the influence of gear on billfish landings corroborate several studies that have linked gear interactions between fisheries with seasonal changes (Monroy-García et al., 2010; Wiyono et al., 2006). Seasonal changes may also influence the availability of target species, which may suggest the reduction in the proportion of landings in the two fisheries in the SEM. Seasonality in fisheries interactions has been observed between commercial and recreational fishers in Rio Grande, Brazil where intra-sectoral competition occurred during the transition months between the wet and dry season when fish were less abundant (de Castro and Begossi, 1996). Competitive interactions due to periods of fishing activity and resource use could be attributed to the strong seasonal component in the recreational billfish landings relative to the artisanal. Findings on the effect of season on billfish landings correlate with earlier studies, which showed that the abundance of striped marlin and to some extent, sailfish in the inshore and offshore waters were influenced by monsoon winds (Abidi et al., 1972; Williams, 1970). These findings also supported the hypothesis that seasonality influenced the proportion of billfish landed in both fisheries. Consequently, the results of this study may reflect the local status of competitive interactions in recreational and artisanal billfish species in Kenya.

The co-occurrence of target species in fishing grounds using the Williamson overlap index (SO_{ij}) emphasizes the dependence of both user groups on the same resource, overlaps in species habitat, and period of activity. The focus on the same species and fishing grounds is indicative of competition between recreational and artisanal fishers. Concentration in the same fishing areas correlates with the ability of user groups to travel to these fishing grounds. The high spatial overlap in recreational areas can be explained by three reasons. First, during the NEM, most of the fishing grounds are accessible by small-scale fishers using small motorized boats (locally referred to as "dinghies") therefore making it possible for the two groups to use the same fishing grounds. Second, the ability of artisanal fishers to diversify their gears makes it possible to fish in most of these locations. Third, most of Kenya's marine fishing activities are concentrated in the near inshore waters, and therefore, there is a high potential for different fishery sectors to operate on the same fishing grounds. Co-occurrence of recreational and artisanal fishers on fishing grounds and during fishing, especially in the NEM, was consistent with previous studies. For example, using ecological concepts such as niche and competition, de Castro and Begossi (1996) reported competitive interactions related to fishing grounds and period of fishing activity between commercial and recreational fishers of Rio Grande, Brazil. Berkes (1984) also observed some form of ecological competition in space where small sportfishing boats were able to frequent areas that were fished by commercial fishing boats in western Lake Erie, Canada, resulting in competitive interactions. In the case of artisanal fishers operating primarily in Watamu, recent years have seen an increase in "dinghies" (Kadagi, pers. comm.). The dinghies have the capability of reaching fishing locations that are frequented by recreational boats. Notably, the combination of dinghies and drift gillnets is bound to increase the overlap in the target species. Thus, there is a need to examine whether the overlap in target species and fishing grounds correlates with the catch rates and fishing pattern of recreational and artisanal billfish fishers. This information will strengthen the argument that these interactions are indeed competitive.

The findings on the significant influence of the fishery type and seasonality changes with the interaction term are consistent with our hypothesis, which predicted that seasonal changes and fishery type would have a substantial effect on mean billfish landings. Changes in the average sea state, especially during the NEM, determined the period of fishing activity. Previous studies have cited an increase in fishing activity during the NEM (Munga et al., 2013; Fulanda et al., 2011). In the case of billfish, the NEM is characterized by two types of billfish runs. The first one is the sailfish run, which occurs between November and January. The second is the marlin run, which has been documented to occur from January through March (Harris et al., 2013; Kadagi et al., 2011). The significant influence of seasonal changes and fishery type could be explained by the increase in fishing activity in the NEM. For instance, sportfishing tournaments and competitions are mostly conducted during NEM, which results in a rise in the numbers of private and charter sportfishing boats (Kadagi et al., 2020).

One observation is that the average billfish landings of recreational fishers declined during the SEM, which is indicative of a decline in fishing activity, given that most sportfishing boats are docked during this period. These findings could be attributed to several reasons. First, the recreational and artisanal sectors fish overlap in the fishing locations; therefore, the distance traveled had no impact on the mean billfish landings. Second, artisanal fishers deployed a variety of fishing gears throughout the fishing year; thus, vessel size may be the least important factor in accounting for the magnitude of billfish landing. However, the findings on the effect of vessel size fail to corroborate with other studies that have shown that the size of the vessel may determine competitive ability among fishing vessels (Rijnsdorp et al., 2000). Large-sized vessels may have powerful engines compared to the small-sized vessels; hence catch rates may increase with high powered vessels (Rijnsdorp et al., 2000).

Given the significant relationship between the mean weight of billfish landings and the interaction between fishery type and season, evaluating trends in fishing activities can improve our understanding of competitive interactions among user groups. A recent census undertaken in major sportfishing clubs noted that the size of the recreational fishing fleet in Kenya has substantially declined from about 100 boats to an average of 40 boats in the past seven years (Kadagi, pers. comm). This is mostly ascribed to the "sailfish drought" and a reduction in the number of international sportfishing anglers. The result of this, as well as angler preferences for other fishing areas, forced some owners of sportfishing vessels to move to different fishing zones (Kadagi, pers. comm.). Hence, there is a need to ascertain the variability in catches, changes in fleet sizes, and the effects of competition for the same fish resources in the Kenyan billfish fishery.

Though this study provides insights into competitive interactions between the two fisheries, we acknowledge several limitations. The use of sailfish and giant trevally as the most common species to determine the co-occurrence of species, as opposed to other species of interest, introduces a bias in the analyses. Further analyses using other species caught by the recreational and artisanal fisheries in the investigations would have been one way to correct for this bias. However, recreational fishers tend to tag mostly billfish and, to some extent, the giant trevally, which dominated the historical tagging data used in the calculations of the Williamson overlap index. Our evaluation of factors influencing billfish landings focused on specific variables (*i.e.,* the effect of seasonal changes, fishery type, distance traveled, and boat size). We recognize that other factors, such as variability in fishing gear specifications, fishing techniques, vessel and engine capacity, species availability, and environmental parameters, may impact billfish landings. Therefore, there is a need to incorporate these factors in future analyses.

5. Conclusions and recommendations

Sources of competitive interactions in the recreational and artisanal billfish fisheries are heterogeneous, underscoring the significance of examining the features of interactions among fishing sectors. The evidence of competitive interactions based on time, space, and resource use presents a unique challenge in understanding the implications of these interactions in the management of shared transboundary fisheries such as billfish. The identification of features for competitive interactions in the two fisheries is a first step for developing a typology for inferring interactions among multiple resource users. Considering the growing aspirations of many countries across the Western Indian Ocean (WIO) to explore the Blue Economy, it is imperative to develop an integrated system (Okafor-Yarwood et al., 2020) that draws on the needs of resource users at the local and regional level while also drawing on fisheries management frameworks that ensure sustainability. A failure to adequately characterize and understand interactions between user groups may negatively impact the livelihoods of fishing communities and the sustainability of natural resources. Our findings emphasize the importance of governance strategies to manage competitive interactions for shared resources, including national and regional fisheries management plans inclusive of all user groups.

Author contributions

NIK conceptualized the study design. NIK and NW collected and collated data from the field and secondary sources. NIK, NW, and RA contributed to the methods section and data analysis. DB contributed to data analysis and interpretation. DB produced Fig. 4. NIK and NW wrote the initial manuscript. All the authors contributed to the revision of the manuscript and approved of its submission.

Ethical considerations

This study obtained a research clearance permit (NACOSTI/P/16/26430/9879) from The Kenya National Commission for Science, Technology, and Innovation (NACOSTI) to conduct surveys across the fishing landing sites. Letters of approval were obtained from the Kilifi County ministry of education and fisheries. This research was also approved under the UF Institutional Review Board (IRB201601621).

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.

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