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# Species Composition of Fisheries Resources of the Tana and Sabaki Estuaries in the Malindi-Ungwana Bay, Kenya

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## Abstract

For over 30 decades, the Sabaki and Tana estuaries of the Malindi-Ungwana Bay, Kenya have supported both the artisanal fishery and semi-industrial bottom trawl sectors. Currently these estuaries in the bay support over 3 000 artisanal fishers and a maximum acceptable fleet of four medium-sized trawlers. These sectors have exerted pressure on the fisheries resources of the bay and will continue to do so due to the increasing artisanal fishing effort. We describe the present status of the fisheries resources of the estuaries in the bay following shore-based catch assessments between 2009 and 2011, and shallow-water bottom trawl surveys in early 2011. These aimed to determine species composition, relative abundance and distribution patterns of the penaeid shrimps and associated trawl fish bycatches, and fish catches from the artisanal fishers. Five shrimp species: *Fenneropenaeus indicus*, *Penaeus monodon*, *Metapenaeus monoceros*, *Penaeus semisulcatus* and *Penaeus japonicus* were recorded. Distinct shrimp species composition existed between the two estuaries characterised by more abundant *F. indicus* in the Tana estuary, and more abundant *P. semisulcatus* in the Sabaki estuary. Bottom trawl fish bycatch species diversity was higher than for artisanal fish catches with a total of 223 and 177 species respectively. Shrimp total biomass and catch rates were significantly higher during the wet Southeast Monsoon (SEM) season than the dry Northeast Monsoon (NEM) season, and decreased as depth increased. On the other hand, trawl bycatch rates were significantly higher in inshore than offshore areas and distinct in composition but less differing between the seasons. Similarity in catch composition was evident between the artisanal catches and bottom trawl bycatches in the inshore areas. This similarity was attributed mainly to seven common and most abundant fish species targeted in artisanal fishery as well as these species made the highest bycatch proportion in the shrimp bottom trawls. Significantly smaller-sized individuals of these seven species occurred in trawl bycatches than in artisanal catches attributed to differences in gear selectivity. Implementation of the present shrimp fishery management plan, and continued monitoring of fish trawl bycatches will be crucial for the effective management of fisheries resources of the estuaries in the bay.

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## Keywords

Species composition • Semi-industrial bottom trawl • Penaeid shrimps • Fish bycatches • Artisanal catches • Tana • Sabaki • Kenya

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## Introduction

The Kenyan coast runs in a south-westerly direction from the border with Somalia in the north at  $1^{\circ} 41'S$  to  $4^{\circ} 40'S$  at the border with Tanzania in the south. It lies in the hot tropical region where the weather is influenced by the monsoon winds of the Indian Ocean. Climate and weather systems are dominated by the large scale pressure systems of the Western Indian Ocean (WIO) and the two monsoon seasons, the dry Northeast Monsoon (NEM) from October to March and the wet Southeast Monsoon (SEM) from April to September (McClanahan 1988). Kenya's coastal ecosystems occupy the western extremity of the tropical Indo-Pacific biogeographic region, and have been classified as part of the Coral Coast of the East African Marine Ecoregion (WWF 2004).

The coastal ecosystems are broadly classified into tropical rainforests, estuarine and nearshore areas, and the open sea (Government of Kenya 2008). These ecosystems include: mangrove swamps, coral reefs, seagrass beds, rocky shores, estuaries, beaches, mudflats, sand dunes and terrestrial habitats, all closely interlinked through various biotic and abiotic fluxes. A wide variety of fish and other marine organisms migrate between ecosystems for breeding, feeding and refugia. An almost continuous fringing reef dominates the inshore areas along the Kenyan coast, except in the Malindi-Ungwana Bay where the river systems of the Sabaki and Tana have created conditions of low salinity and high turbidity especially during the wet SEM season, with limited coral growth.

The distribution of these coastal ecosystems is also influenced by the coastal geology and oceanography. The interactions between the north-flowing East African Coastal Current (EACC) and the seasonal south-flowing Somali Current (SC) create a temperature gradient of warm to cool from south to north. This affects the productivity of the open sea ecosystems, resulting in the development of coral reefs in the cooler, nutrient-rich waters of the north, and extensive mangrove, seagrass and suspension-feeding communities towards the south. The rich biodiverse coastal ecosystems provide critical socio-economic and ecological services such as protection from storm surges, food, wood fuel, and livelihoods for the local communities. In the lower Sabaki and Tana River flood plains and oxbow lakes, subsistence fisheries of brackish and freshwater species of Protopteridae (lungfishes), Claridae (catfishes), Cichlidae (tilapines), Anguillidae (eels), and prawns (*Macrobrachium* sp.) is common. These vital coastal ecosystems are on the other hand, facing threats from ever increasing human pressure through tourism, industrial pollution, inshore overfishing, mangrove logging (Tychsen 2006), commercial salt mining and the ongoing offshore gas and oil exploration (pers. obs.).

Sustainable management of coastal artisanal fisheries in the tropics is challenging due to the multigear, multispecies and multifleet nature and the lack of adequate resources to conduct scientific studies, monitoring and enforcement (McClanahan and Mangi 2004). There is a growing awareness that reliable knowledge on trends in catch composition and selectivity of commonly used gear is important for management recommendations (Gobert 1994; McClanahan and Mangi 2004). The artisanal fishery is receiving increasing attention from scientists and environmental managers for both ecological and socio-economic reasons, including user conflicts, habitat destruction and stock depletion. The current climate change phenomenon has threatened species composition of reef-based fisheries as reef habitats are getting destroyed under unprecedented pressure (Cinner et al. 2009). In the Malindi-Ungwana Bay, artisanal fisheries is restricted to the inshore fishing grounds of <3 nautical miles (nm) off the Sabaki and Tana estuaries due to inability of the artisanal fishers to access offshore fishing grounds. These inshore fishing grounds, are also the main shallow water shrimp trawling grounds (Mwatha 2005; Munga et al. 2012; Munga et al. 2013) causing user conflict between the artisanal fishers and semi-industrial shrimp trawlers. The shrimp fishery management plan 2010 ensures sustainable shrimp exploitation by restricting trawl fishing grounds and limiting trawling effort as a way to reduce conflicts between the trawl and artisanal fishery sectors.

Recent estimates place the number of artisanal fishers in the bay at >3 000, with around 1 000 fishing crafts, ranging from dugout canoes used near the shore to large dhows for open sea fishing (Government of Kenya 2014). The number of artisanal fishers is expected to increase as a result of population growth. Catches of the artisanal fishery comprise a multi-species mix of demersal fishes (50% by weight), pelagic fishes (28%), and the rest 22% made up of sharks and rays, octopus and squid, shrimps, lobsters and crabs (Government of Kenya 2010; Munga et al. 2012, 2014). This species mix is typical of artisanal fisheries in the South West Indian Ocean (Jiddawi and Öhman 2002; van der Elst et al. 2005).

The semi-industrial bottom trawl fishery was initiated after a series of successful surveys undertaken by the Kenya Government, UNDP and FAO in early 1960s (Iversen 1984; Venema 1984; Saetersdal et al. 1993). Bottom trawling thereafter, continued for several decades, landing an average 400 tonnes of shrimps annually in the 1970s, 80s and 90s (Mwatha 2005). The government however, temporarily closed the shrimp trawl fishery in 2006, as a result of user conflicts between trawlers and artisanal fishers over declining catches, artisanal fishing gear destruction, perceived environmental degradation, and excessive trawl bycatches whose low market prices competed unfairly with artisanal catches (Fulanda et al. 2009, 2011; Munga et al. 2012). Trawl catches in the bay include shrimps and a large bycatch of fish, sharks, rays, crustaceans and other

invertebrates (Fennessy et al. 2004, 2008). Although some of the bycatch is retained and sold, most has low commercial value, and is discarded overboard. The trawl fishery resumed in 2012 with a maximum of four trawlers but the spatio-temporal management strategy of Ungwana Bay remains under review.

This paper aims to investigate the spatial and temporal patterns in the composition of the bottom trawl catches (shrimps and bycatches) and of catches made by the artisanal fishers as well as to assess the extent of resource-use overlap between the two sectors in the bay. Factors taken into account in comparisons were seasons (SEM *versus* NEM) and fishing areas (inshore *versus* offshore). This information is important for the development of spatio-temporal fisheries management strategies to mitigate against resource-use conflict in the estuaries of the bay.

## Material and Methods

### The Study Area

The Malindi-Ungwana Bay comprises of the larger northward Ungwana Bay and the smaller southward Malindi Bay, and lies off the East African coast in the Western Indian Ocean (WIO) region (Fig. 1). The bay is located between the latitudes 2° 30'S and 3° 30'S, and the longitudes 40° 00'E and 41° 00'E and extends from Malindi through Ras Ngomeni in the south to Ras Shaka in the north covering a distance of about 200 km long. It encompasses the fishing grounds of Sabaki and Tana river estuaries. Administratively, the Malindi-Ungwana Bay is located within the two counties of Malindi and Tana River with populations of 281,600 and 181,000 respectively out of a population of about 3 million for the entire coastal area, about 8% of the Kenyan population (Government of Kenya 2002). The bay including the North Kenya Bank covers a total trawlable area of 10,994 km<sup>2</sup> against a total estimate of 19,120 km<sup>2</sup> of the entire Exclusive Economic Zone (Mutagyeru 1984). The bay around the Tana outflow is shallow and extends between 8 and 32 nm. The mean depth at spring high tide is 12 m at 1.5 nm, and 18 m at 6.0 nm from the shore. The depth increases rapidly to 100 m after 7 nm from the shore. Near the Sabaki outflow, the offshore distance stretches between 3 and 5 nm, whereafter depth rapidly increases to 40 m (Kitheka et al. 2005; Kitheka 2013). Critical habitats along the bay include mangrove forests, patchy reefs, islets, sandy shores and tidal flats. The Sabaki estuary is also an Important Bird Area (IBA) as it hosts large visiting flocks of Madagascar pratincole, and important resting, roosting and feeding ground for gulls and terns (Tychsen 2006). Climate and weather systems are dominated by the large scale pressure systems of the WIO and the two monsoon seasons, the dry NEM and the wet SEM.

### Bottom Trawl Data Collection for Shrimps and Fish Bycatches

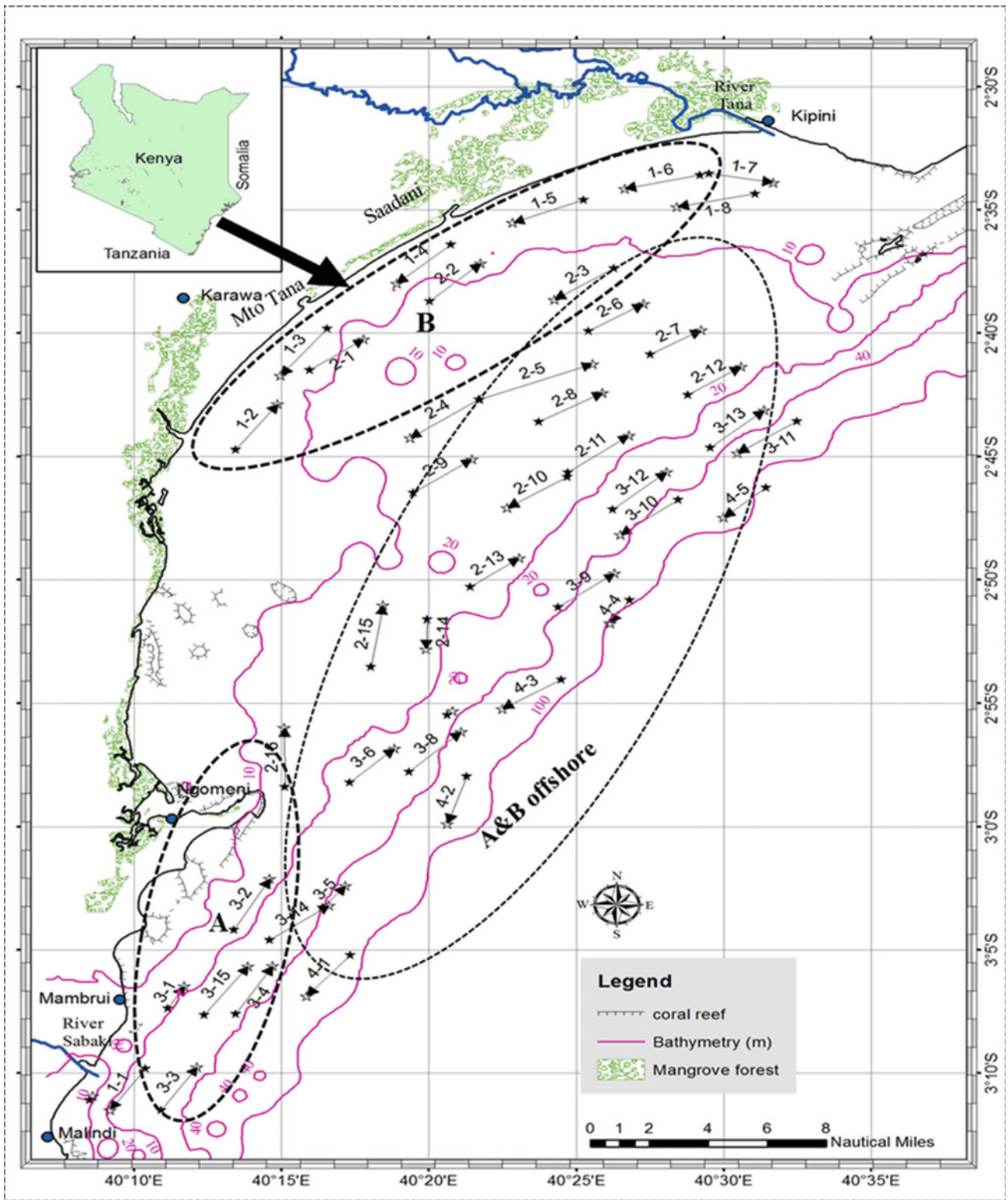
Two bottom trawl surveys were conducted during January–February (NEM) and May–June 2011 (SEM) using a commercial shrimp trawler. A total of 41 and 36 tows were made roughly parallel to the shoreline in NEM and SEM seasons respectively, with total trawled areas of 546.4 nm<sup>2</sup> and 507.7 nm<sup>2</sup> each. All unwanted debris, plants and large organisms were first removed from catches, whereafter the remainder were sorted into fish and shrimp categories. Total catches of shrimps were weighed, a 2 kg sub-sample for large catches, and the entire catch for small catches, were frozen for species identification in a laboratory. The remainder of the fish component was divided into mixed equal portions, and one portion was randomly sampled after large fish were first removed and weighed separately. The total catch of each species from each tow was calculated by multiplying the sub-sample by a raising factor derived from the sub-sample to total shrimp or fish catch weight (see Stobutzki et al. 2001; Tonks et al. 2008). The FAO species identification sheets for the WIO (Fischer and Bianchi 1984) were used for shrimps and all fish were identified according to Smith and Heemstra (1998), Lieske and Myers (1994), and van der Elst (1981). Sub-samples from representative proportions of fish were weighed and measured using a fixed marked ruler on a flat board (TL, cm).

### Data Collection for Artisanal Fish Catches

Shore-based artisanal catch assessments were undertaken between 2009 and 2011. In 2009 during the months of June, November and December; in 2010 (March, June and September), and in 2011 during the months of March, July and September along the three fishing areas of Malindi (39 assessments), Ngomeni (27 assessments) and Kipini (18 assessments) (Fig. 1) totalling to 49 shore visits and 84 samples covering both NEM and SEM seasons. Number of fishers and active fishing time (h) excluding navigation time to and from the fishing grounds were recorded. A total of 9,502 kg of fish was weighed during the entire exercise, and a sub-sample of 2,237 kg (24%) more than the recommended 10% representative proportion (Stobutzki et al. 2001; Tonks et al. 2008) was used for the enumeration of number of individuals per species, identification of species and TL measurements. Fish identification and measurements followed the same procedure as that for the trawl fish bycatches.

### Data Analyses for Bottom Trawl Shrimps and Fish Bycatches

For the trawl surveys, shrimp and fish biomasses were calculated using the swept area method (Spar and Venema 1998).



**Fig. 1** A map of Malindi-Ungwana Bay, Kenya, showing the grouping of trawl stations at the Sabaki (A) and Tana (B) inshore area, and offshore (area A & B). Figures on the map indicate station number and depth stratum respectively. Station 1–2 means station No. 2 in depth stratum 1. Malindi, Ngomeni and Kipini were the fishing areas where artisanal catches were sampled

The swept area ( $a$ , nm<sup>2</sup>) or ‘effective path swept’ for each tow was calculated as:

$$a = D \times h \times X$$

where  $D$  is the distance covered in nm ( $D = 60 \times \sqrt{(Lat_1 - Lat_2)^2 + (Lon_1 + Lon_2)^2 \cos 0.5^2 (Lat_1 + Lat_2)}$ ),  $h$  is the length of the head-rope (m), and  $X$  is the fraction of the head-rope length equal to the width of the path swept by the trawl. The value of  $X$  was set at 0.5 in this study (Pauly 1980).

Shrimps and bycatch rates were calculated as catch ( $C$ , kg) divided by the time spent trawling ( $t$ , hrs) and converted to catch-per-unit-area (CPUA, kg/nm<sup>2</sup>) by dividing by the swept area ( $(C/t) / (a/t) = C/a$ ).

Total biomass ( $B$ , kg) was calculated from:

$$B = \frac{\left(\overline{C/a}\right) \times A}{X_1}$$

where  $C/a$  is the CPUA of all tows (kg/nm<sup>2</sup>),  $A$  is the overall area under investigation (nm<sup>2</sup>), and  $X_1$  is the estimated proportion of shrimp or fish bycatch present in the area swept. We assumed that all shrimps would be captured, and that not all fish in the path of the tow would be captured (i.e.  $X_1 = 1$  and  $X_1 = 0.5$  respectively). The total biomass of shrimps and fish for the entire surveyed area (546.4 nm<sup>2</sup>) was calculated from 41 tows made in the NEM season and 37 tows in the SEM season.

The multivariate non-metric multi-dimensional scaling (MDS) technique was used to identify whether geographical areas (inshore and offshore) or seasons (NEM and SEM) affected the community compositions of both trawl and artisanal catches based on Bray-Curtis similarity using PRIMER v6 (Clarke and Warwick 2001). The area and seasonal differences were further analysed by 2-way crossed ANOSIM with area and season as factors. The most influential species to the dissimilarity were identified using 2-way SIMPER. A 2-way ANOVA, followed by post hoc pair-wise comparison by Tukey HSD test, and test of homoscedascity of variance (Levene’s test) was used to test for significant differences in trawl bycatch rates (kg/h) and biomass (CPUA) between areas and seasons. Catch rates for the artisanal fishery were defined as kg/fisher.  $h$  and 1-way ANOVA was used to test for significant differences between the seasons. Measures of diversity using species richness ( $S$ ) and Shannon-Wiener diversity index ( $H'$ ) were calculated for fishes caught by shrimp trawlers and those caught by artisanal fishers, and these were compared between the two sectors for the two seasons using ANOVA. Sizes of fishes caught by shrimp trawlers were compared with those caught by artisanal fishers and differences tested using either the parametric

2-way ANOVA or non-parametric Kruskal-Wallis depending on homoscedascity of the data. All the parametric and non-parametric tests were done using STATISTICA v.

## Results

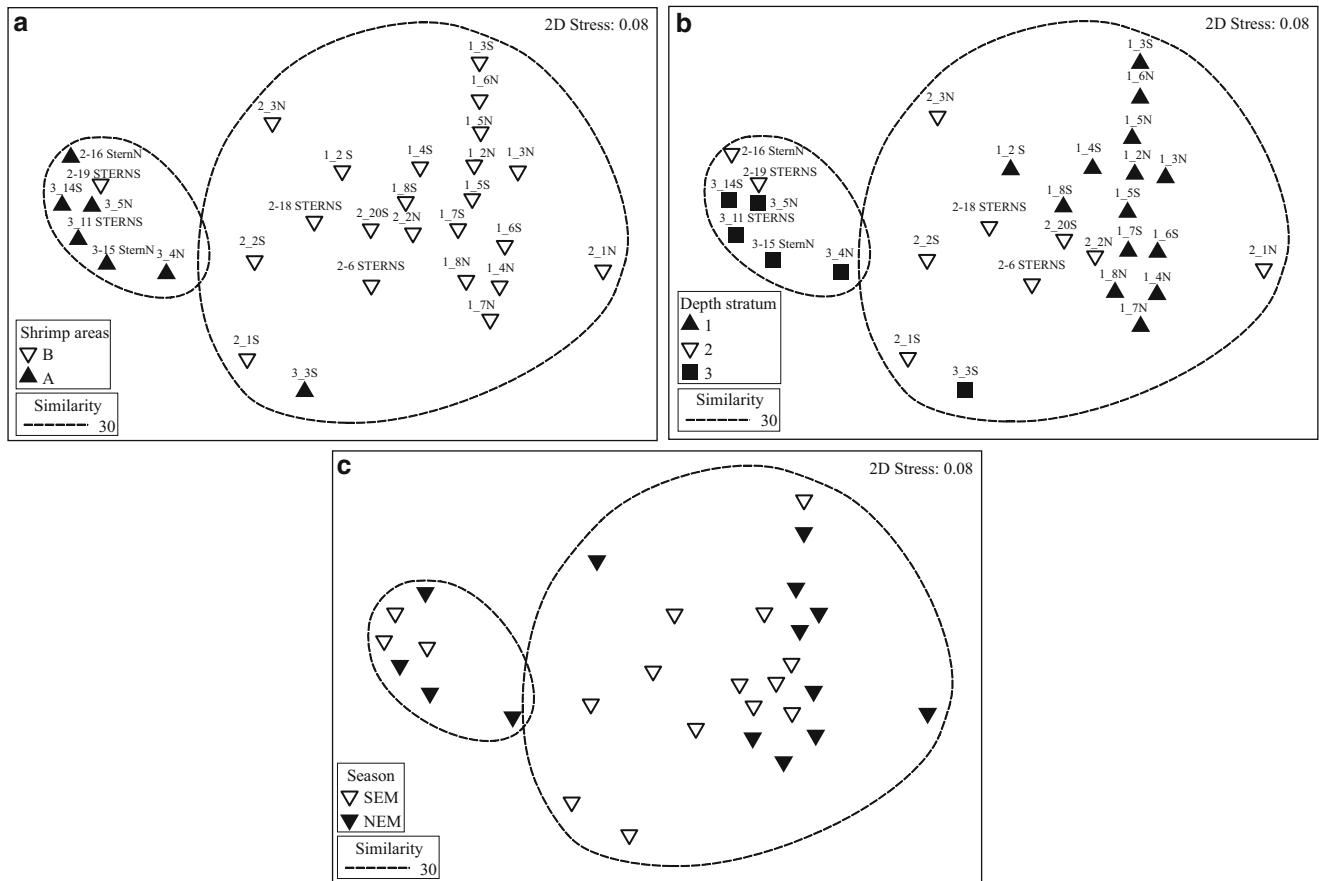
### Shrimp Distribution Patterns, Composition and Abundance

The MDS plots (Fig. 2) showed a distinct separation of shrimp species composition by geographical area and by depth, but not by season. Pair-wise comparison tests indicated species composition at 0–10 m depth differed significantly from those at 10–20 m and 20–40 m ( $R = 0.337$ ;  $p = 0.002$  and  $R = 0.970$ ;  $p = 0.001$  respectively), and that composition at 10–20 m differed from 20–40 m ( $R = 0.248$ ;  $p = 0.047$ ).

The difference in shrimp composition between areas was due to more abundant *P. semisulcatus* in area A (Sabaki; on average 82.2%), and more abundant *F. indicus* in area B (Tana; 52.8%; Table 1). By area, *P. semisulcatus* contributed the highest dissimilarity (36.6%) and *F. indicus* followed with 26.9%. The least contributing species to the dissimilarity were *M. monoceros*, *P. monodon* and *P. japonicus* (12.5%, 5.1% and 1.8% respectively). Two-way SIMPER analysis based on depth and season indicated that *F. indicus* was most abundant in 0–10 m (66.2%) and *P. semisulcatus* in 20–40 m depth (81.1%). Neither *F. indicus* nor *P. japonicus* were recorded at 20–40 m depth.

Seasonal differences in shrimp species composition were non-existent for *P. semisulcatus*, *F. indicus* and *P. japonicus*, but existed for more abundant *M. monoceros* during SEM and more abundant *P. monodon* during NEM (Table 1). The seasonal dissimilarity depended mostly on *F. indicus* (14.6%), followed by *M. monoceros* (11.8%) and *P. semisulcatus* (10.4%). *P. semisulcatus* contributed on average 90% (NEM) and 72% (SEM) by numbers to catches in the south of the bay, Malindi-Sabaki area A, followed by *M. monoceros* (6% in NEM and 25% in SEM). Five penaeid shrimp species were recorded in north of the bay, Tana area B in both seasons; *F. indicus* contributed 60% (NEM) and 48% (SEM), followed by *M. monoceros* (16% and 29%). *P. japonicus* was the least abundant, irrespective of area, depth or season.

The combined data for all shrimp species, including both seasons and all depths shallower than 40 m, indicated that shrimps were more abundant in the Tana area (3.76 kg/hr) than in the Malindi-Sabaki area (0.82 kg/hr). The overall shrimp catch rate and biomass during the SEM (6.17 kg/hr and 251 203 kg) were higher than during the NEM survey



**Fig. 2** Non-metric MDS plots (with indication of similarity levels of 30) showing the composition of shrimps by (a) area, (b) depth stratum and (c) season in the Malindi-Ungwana Bay, Kenya, based on shrimp

species abundance for the combined Northeast Monsoon (NEM) and Southeast Monsoon (SEM) surveys

**Table 1** Two-way SIMPER analysis: Shrimps species contributing to the dissimilarity in terms of abundance (%) by area (area A = Sabaki; area B = Tana) and by season (NEM = Northeast Monsoon survey;

SEM = Southeast Monsoon survey) levels. The average dissimilarity was 82.9 and 45.7%, respectively

Species	Area analysis				Seasonal analysis			
	Abundance (avg. %)		Dissim. (avg. %)	Contrib. (%)	Abundance (avg. %)		Dissim. (avg. %)	Contrib. (%)
	Area A	Area B			NEM	SEM		
<i>Penaeus semisulcatus</i>	82.2	12.2	63.6	44.2	29.3	27.8	10.4	22.8
<i>Fenneropenaeus indicus</i>	0.0	52.8	26.9	32.4	42.6	38.7	14.6	31.9
<i>Metapenaeus monoceros</i>	13.9	23.4	12.5	15.0	13.3	28.1	11.8	25.8
<i>Penaeus monodon</i>	2.3	9.1	5.1	6.2	11.1	4.4	6.6	14.5
<i>Penaeus japonicus</i>	1.6	2.5	1.8	2.2	3.7	1.1	2.3	5.0

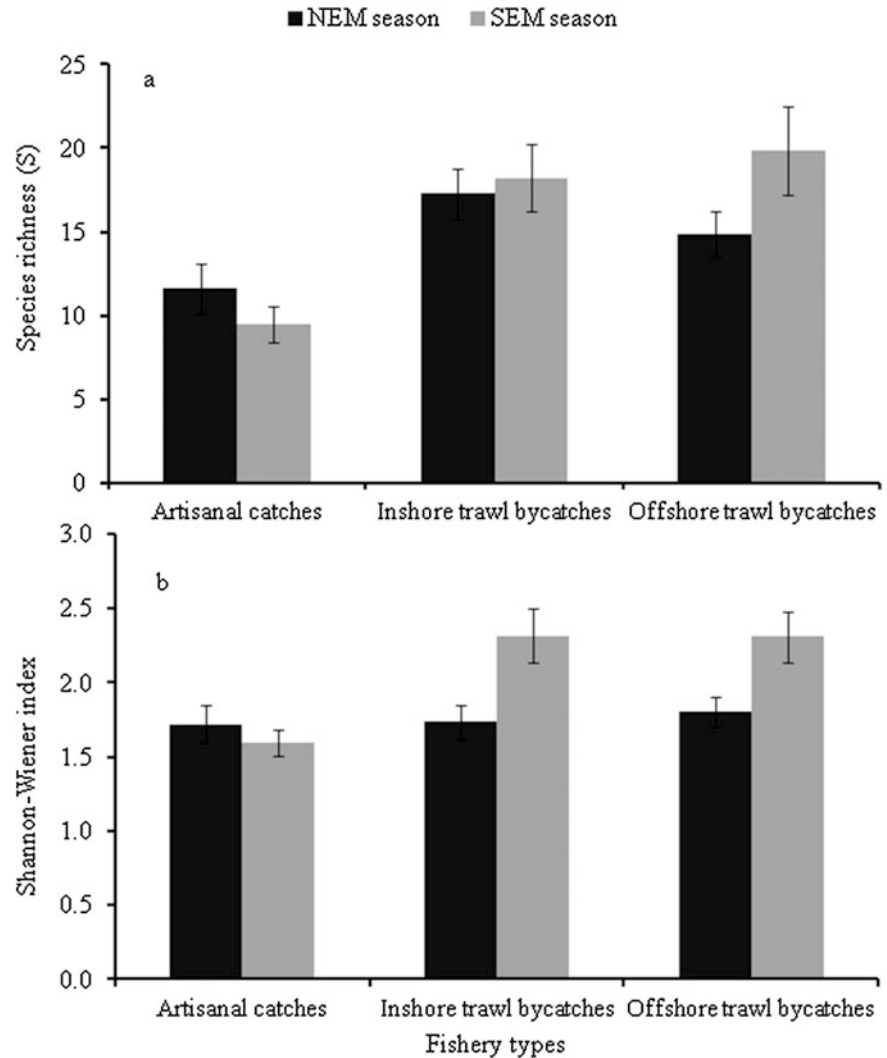
(1.45 kg/hr and 74 570 kg). In both surveys, biomass was greatest at the shallowest depth (0–10 m), and no shrimps were caught deeper than 40 m. Results of 2-way ANOVA indicated shrimp catch rates and biomass differed significantly between depths and seasons, and that the effect of the depth-season interaction was insignificant ( $<0.05$ ; Table 2).

### Comparison of Fish Composition Between Trawl Bycatches and Artisanal Catches

A total of 158 and 161 fish species from trawl bycatch against 90 and 148 species from artisanal catches were recorded during the NEM and SEM seasons respectively. Overall, trawl bycatches constituted a total of 223 species, and 177 species

**Table 2** Results of 2-way ANOVA showing significant differences in shrimp catch rates (kg/h) and biomass (kg/nm<sup>2</sup>) between seasons, depth strata and the interaction of season and depth stratum, in Malindi-Ungwana Bay, Kenya

Factors	Df	Error Df	Catch rate (kg/h)		Biomass (kg/nm <sup>2</sup> )	
			F	p-value	F	p-value
Season	1	23	9.138	<b>0.006</b>	8.531	<b>0.008</b>
Depth stratum	2	23	4.397	<b>0.024</b>	3.872	<b>0.036</b>
Season × Depth stratum	2	23	1.748	0.197	1.670	0.210

**Fig. 3** Comparison of mean ( $\pm$ SE) species richness (a) and Shannon-Wiener diversity index (b) per sample between artisanal catches and trawl bycatches during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in Malindi-Ungwana Bay, Kenya

for the artisanal catches. Species richness ( $S$ ) for artisanal catches was higher during the NEM season (on average 12 per sample) and lower during SEM season (on average 9 per sample), while for the inshore trawl bycatches, species richness was almost similar between the seasons (on average 18 and 17 per tow for the SEM and NEM respectively; Fig. 3a); and for the offshore bycatches, species richness was higher in SEM than NEM (on average 20 and 15 per tow respectively). The Shannon-Wiener diversity index ( $H'$ ) for the artisanal catches was almost similar between the seasons (on average 1.7 and 1.6

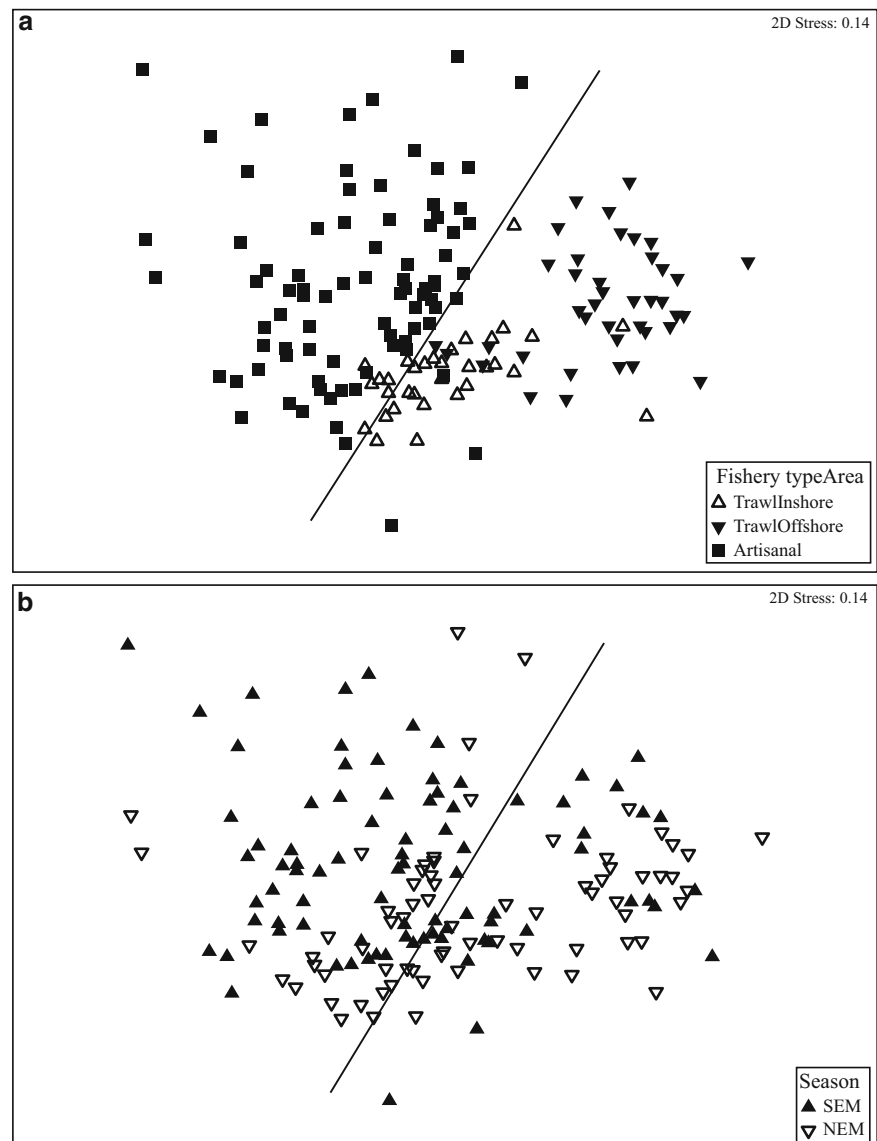
per sample for the NEM and SEM respectively), and for both the inshore and offshore bycatches, it was higher in SEM (on average 2.3 per tow each) and lower in NEM (on average 1.7 and 1.8 per tow respectively, Fig. 3b).

There was a significant difference in species richness between the fishery sectors (2-way ANOVA:  $p < 0.05$ ) but not between seasons, nor was there a significant effect due to the interaction of fishery sector with season ( $p > 0.05$ , Table 3). Post hoc pair-wise comparison showed significantly higher species richness for the trawl bycatches in both seasons

**Table 3** Results of 2-way ANOVA showing significant differences in finfish species richness between fishery types (trawl bycatches and artisanal catches) and significant differences in Shannon-Wiener diversity index between fishery types, seasons and the interaction of fishery type with season in the Malindi-Ungwana Bay, Kenya (p-value bold and italic are significant)

Factors	Df	Error Df	Species richness (S)		Shannon-Wiener diversity index (H')	
			F	p-value	F	p-value
Area	2	149	14.718	<b>&lt;0.001</b>	6.794	<b>0.002</b>
Season	1	149	0.834	0.363	8.178	<b>0.005</b>
Area × Season	3	149	2.726	0.069	5.089	<b>0.007</b>

**Fig. 4** Non-metric MDS plots showing the composition of fish catches in Ungwana Bay: (a) by fishing sector [artisanal, inshore and offshore trawl]; and (b) by season [NEM and SEM for combined artisanal and trawl bycatches]. The *dotted lines* separate artisanal from trawl bycatches



( $p < 0.05$ ). The same test showed significant differences in Shannon-Wiener diversity index between the fishery sectors, seasons and a significant effect due to the interaction of fishery sector with season ( $p < 0.05$ , Table 3). Post hoc pair-wise comparison indicated significantly higher Shannon-Wiener diversity index for the inshore and offshore trawl bycatches during both seasons ( $p < 0.05$ ).

The non-metric MDS plots (Fig. 4a) showed a distinct species composition between the artisanal catches and trawl bycatches (inshore and offshore), and to some extent between the seasons (Fig. 4b). There was a significant difference between the fishery sectors, and to a lesser extent between the seasons (2-way ANOSIM:  $R = 0.317$ ;  $p = 0.001$  and  $R = 0.088$ ;  $p = 0.003$  respectively). Pair-wise comparison

tests showed the inshore trawl bycatches differed significantly from the offshore trawl bycatches ( $R = 0.631$ ;  $p = 0.001$ ), but not from the artisanal catches ( $R = 0.066$ ;  $p = 0.090$ ). Also the offshore trawl bycatches significantly differed from the artisanal catches ( $R = 0.460$ ;  $p = 0.001$ ). The differences in composition between offshore trawl bycatches and artisanal catches from the results of 2-way SIMPER was due to more abundant species of *Bothus mancus*, *Trachinocephalus myops*, *Callionymus gardineri* and *leiognathus lineolatus* in offshore trawl bycatches, and more abundant *Lobotes surinamensis*, *Lutjanus fulvivflamma*, *Galeichthys feliceps*, *Psettodes erumei* and *Pellona ditchela* in artisanal catches. The seasonal differences in composition between the fishery sectors was due to more abundant *G. feliceps*, *P. ditchela*, *B. mancus*, *Thryssa vitrirostris* and *T. myops* in NEM, and more abundant *P. erumei* in the SEM season (2-way SIMPER analysis).

A total of seven common and most abundant fish species explained the similarity between inshore trawl bycatches versus artisanal catches (Table 4; 2-way SIMPER analysis). The relative abundance of these species was higher both in inshore trawl bycatches and artisanal catches than those in offshore trawl bycatches. Size comparison of these seven species between artisanal catches and trawl bycatches showed that except for *Lobotes surinamensis* all the species were significantly smaller in size for the trawl bycatches than for the artisanal catches ( $p < 0.05$ ), while seasonal differences in sizes were only significant for *L. surinamensis* and *Leiognathus equulus* ( $p > 0.05$ , Table 5).

**Table 4** Two-way SIMPER analysis: Species contributing most to similarity in terms of abundance (%) between inshore trawl bycatches (within similarity of 23.3%) and artisanal catches (within similarity of 9.3%) in Ungwana Bay, Kenya

Species	Average abundance	Average similarity	% contribution
<b>Inshore trawl bycatches</b>			
<i>Galeichthys feliceps</i>	14.65	5.27	22.59
<i>Pellona ditchela</i>	9.12	2.79	11.97
<i>Johnius amblycephalus</i>	6.68	1.95	8.35
<i>Leiognathus equulus</i>	3.54	1.30	5.57
<i>Pomadasys maculatus</i>	4.05	1.10	4.71
<i>Otolithes ruber</i>	2.36	0.84	3.61
<i>Lobotes surinamensis</i>	0.95	0.22	0.96
<b>Artisanal catches</b>			
<i>Lobotes surinamensis</i>	7.52	1.40	14.98
<i>Galeichthys feliceps</i>	5.20	0.80	8.61
<i>Pellona ditchela</i>	4.09	0.70	7.45
<i>Otolithes ruber</i>	3.90	0.58	6.23
<i>Pomadasys maculatus</i>	2.50	0.30	3.17
<i>Leiognathus equulus</i>	1.24	0.13	1.44
<i>Johnius amblycephalus</i>	1.15	0.12	1.33

**Table 5** Mean total lengths (cm  $\pm$  SE) of the most abundant artisanal target fish species which occurred in trawl bycatches during the North-east Monsoon (NEM) and Southeast Monsoon (SEM) seasons in

Malindi-Ungwana Bay, Kenya with trawl bycatches indicating significantly smaller individuals than those in artisanal catches ( $p < 0.05$ , bold and italic)

Species	Artisanal	Trawl	N/Error Df	Statistic	p-value
<i>Galeichthys feliceps</i>	39.8 $\pm$ 1.3	20.5 $\pm$ 0.3	357	227.171	<b>&lt;0.001</b>
<i>Johnius amblycephalus</i>	14.4 $\pm$ 1.8	11.4 $\pm$ 2.2	228	51.819	<b>&lt;0.001</b>
<i>Pellona ditchela</i>	14.8 $\pm$ 0.4	13.6 $\pm$ 0.1	787	8.272	<b>0.004</b>
<i>Lobotes surinamensis</i>	56.2 $\pm$ 0.9	55.1 $\pm$ 1.7	298	3.045	0.082
<i>Otolithes ruber</i>	24.3 $\pm$ 0.3	18.9 $\pm$ 0.2	380	165.400	<b>&lt;0.001</b>
<i>Leiognathus equulus</i>	12.5 $\pm$ 0.2	13.3 $\pm$ 0.1	448	19.218	<b>&lt;0.001</b>
<i>Pomadasys maculatus</i>	21.9 $\pm$ 0.6	12.9 $\pm$ 0.1	289	299.596	<b>&lt;0.001</b>
	NEM season	SEM season			
<i>Galeichthys feliceps</i>	25.8 $\pm$ 0.7	24.4 $\pm$ 0.7	357	0.129	0.719
<i>Johnius amblycephalus</i>	11.9 $\pm$ 2.5	11.8 $\pm$ 2.2	228	0.960	0.328
<i>Pellona ditchela</i>	14.4 $\pm$ 0.4	14.0 $\pm$ 0.1	787	0.002	0.968
<i>Lobotes surinamensis</i>	59.4 $\pm$ 1.3	53.2 $\pm$ 1.0	298	12.823	<b>&lt;0.001</b>
<i>Otolithes ruber</i>	21.4 $\pm$ 0.3	20.9 $\pm$ 0.3	380	1.093	0.296
<i>Leiognathus equulus</i>	13.4 $\pm$ 0.2	12.7 $\pm$ 0.1	448	13.349	<b>&lt;0.001</b>
<i>Pomadasys maculatus</i>	17.1 $\pm$ 0.4	16.6 $\pm$ 0.5	289	2.857	0.910

## Discussion

### Shrimp Distribution Patterns, Composition and Abundance

The distribution of shallow-water penaeid shrimps was restricted to the nearshore areas of the Sabaki and Tana estuaries of the Malindi-Ungwana Bay, and no shrimps were caught further offshore (Fig. 1). The species composition and abundance patterns differed between these estuaries: all five shrimp species were recorded at the Tana estuary in both the NEM and SEM seasons, whereas only three species (*P. semisulcatus*, *M. monoceros* and *P. monodon*) were recorded at the Sabaki estuary during the SEM. *Fenneropenaeus indicus* was the most abundant species at the Tana estuary, coinciding with the more turbid environment. Turbid waters in Maputo Bay, Mozambique also coincided with areas of high *F. indicus* catches by commercial trawlers, and turbidity also affected the distribution of *F. indicus* and *M. monoceros* at Saco da Inhaca (Macia 2004). Juvenile *F. indicus* and *M. monoceros* inhabited turbid waters with reduced visibility to escape predators (Macia 2004; de Freitas 2011). *F. indicus* in the present study was not recorded in the less turbid and deeper Sabaki estuary.

*Penaeus semisulcatus* dominated shrimp catches in the Sabaki estuary, and previous studies from the Western Indian Ocean (WIO) region showed that this species prefers low turbidity, muddy substrates and deeper water, where it is often associated with sea grass meadows (Macia 2004; Forbes and Demetriades 2005; de Freitas 2011). *P. semisulcatus* is a naturally burrowing species during daytime, but feeds during the night when it can be fished more successfully (Hughes 1966; Vance et al. 1994; de Freitas 1986; 2011). Post-larval and young adult *P. semisulcatus* are often associated with submerged macrophytes, especially in estuarine backwaters, and adults prefer deeper waters (3–20 m) in large bays and offshore shelf areas (de Freitas 1986, 2011). Macia (2004) observed that *P. semisulcatus* preferred deeper water bays compared to *F. indicus*; our findings agree with this observation. *P. monodon*, *M. monoceros* and *P. japonicus* inhabited both Tana and Sabaki areas, suggesting that they have a broader tolerance to factors that may limit *F. indicus* distribution in the bay. Forbes and Demetriades (2005) also suggested that *M. monoceros* can inhabit diverse habitats, from areas with submerged macrophytes to deeper reaches of mangrove swamps in low salinity environments.

The relatively shallow depth associated with sandy bottom and high turbidity, especially during the SEM season, favoured the existence of higher shrimp biomass at the Tana, compared to the Sabaki estuary. Fulanda et al. (2011) and Munga et al. (2012) also reported higher shrimp catch rates

at the Tana estuary during the SEM than NEM season, using longer term commercial bottom trawl data. Similar seasonal variation in shrimp catch rates were also reported for the Tanzanian commercial bottom trawl and artisanal fisheries (Semesi et al. 1998; Teikwa and Mgaya 2003).

### Composition of Trawl Bycatches and Artisanal Catches

The Malindi-Ungwana Bay is sub-divided into use zones according to the shrimp fishery management plan 2010 (Fulanda et al. 2011; Government of Kenya 2014). The 0–3 nm is the inshore area designated for the artisanal fisheries exploitation and therefore, excludes shrimp trawling. The zone beyond 3 nm offshore is the area designated for bottom trawling activities. Before the trawling ban in 2006, trawlers contravened this zonation and trawled in the inshore area and therefore, resulted into user conflict with the artisanal fishery. In this present study we use the terms inshore and offshore areas to identify resource-use overlap between the two fishery sectors that could have necessitated the conflict. Both agriculture and fisheries are important food sectors within the Tana River County where the largest section of the Malindi-Ungwana Bay falls. Agriculture production in this county has over the years been affected by unfavourable weather patterns of long dry spells and flush floods. Artisanal fishing effort is therefore, expected to increase in the bay (Government of Kenya 2014), and the implementation and enforcement of the existing management plans are therefore crucial if conflict is to be reduced.

Catch rate and abundance comparisons between artisanal and trawl bycatch data are relative only, because of different methods of calculation, and of collecting data. Results indicated that trawl bycatch rates and biomass decreased from inshore to offshore areas of the estuaries in the bay. This pattern is reflected due to differences in depth distribution by individual fish species. Studies of differences in spatial distributions of bycatch species showed preferences for six species of elasmobranchs on Tugela Bank of South Africa (Fennessy 1994). Similarly, bycatches of flatfishes (Paralichthyidae) were distributed over a broader spatial range than the Pleuronectidae in the Gulf of California (Rabago-Quiroz et al. 2008). The bycatch of *Galeichthys feliceps*, *Pellona ditchela*, *Johnius amblycephalus*, *Leiognathus equulus*, *Pomadasys maculatus*, *Lobotes surinamensis* and *Otolithes ruber* were more abundant in the inshore area (Tana and Sabaki estuaries), where they also form a target catch of the artisanal fishery and therefore, the source of resource-use overlap with the bottom trawling. Conversely *Trachinocephalus*

*myops* and *Bothus mancus*, less targeted in the artisanal fishery, were more abundant in offshore waters of these estuaries.

Apart from catching a high diversity of fish bycatch, tropical shrimp trawl fisheries are also associated with large volumes of bycatch that consist mostly of under-sized and immature individuals. This present study was no exception. Six of the seven most common and abundant fish species were of significantly smaller-sized individuals in the inshore trawl bycatch than in the artisanal catches. With continued and intensive trawling especially in the inshore area, such affected bycatch species which are otherwise a target in the artisanal fishery, are possibly given less time to recruit before capture or may be totally depleted. This scenario may possibly explain why the Malindi-Ungwana Bay artisanal fishery after a long period of trawling activity before the trawling ban in 2006, had started experiencing reduced artisanal catches (Munga et al. 2012), and this needs to be considered for further management. In addition, the small-sized individuals of a majority of trawl bycatches especially in offshore, were composed of low commercial value species of *Bothus mancus*, *Callionymus gardineri*, *Aluterus monoceros* and *Apogon fasciatus* as found in the Gulf of California (Rabago-Quiroz et al. 2008). These authors reported the majority of trawl bycatch fish species sampled in a survey off the Gulf of California to be mostly small-sized individuals ranging between 6 – 18 cm in total length. Since tropical shrimp trawl bycatch species richness is high, coupled with many small-sized and juvenile individuals, there is a high risk of reduced species diversity and to some extent disappearance of certain species, as observed by Chong et al. (1987) when assessing the effects of a 1978 sustained ban on trawling in an Indonesian shrimp fishery. So far in the Sabaki and Tana estuaries of the Malindi-Ungwana Bay, no single study has established a complete disappearance of species due to the impact of trawling, but reduced catches in the artisanal fishery before the trawl ban in 2006 have been confirmed to some extent (Munga et al. 2012). In order to avoid this risk of biodiversity loss, emphasis on the use of effective Bycatch Reduction Devices (BRDs) that allow escape of small-sized and juveniles should be made mandatory in the estuaries of the bay. This is in addition to restriction of bottom trawling activity within the inshore area.

## Conclusions

Shrimp abundance in the Tana and Sabaki estuaries of the Malindi-Ungwana Bay is concentrated near the outflows of the estuaries, and these two estuaries have distinct species compositions, with *F. indicus* dominating in the Tana

estuary and *P. semisulcatus* in the Sabaki estuary. The total biomass of shrimps and fish bycatch decreased with increasing depth, and was higher during the wet SEM than the dry NEM season.

The inshore areas of the Sabaki and Tana estuaries of the bay, are accessible to an increasing number of artisanal fishers (Government of Kenya 2014), and are richer in fish abundance and diversity than the offshore areas. The most abundant and affected fish species which are also a target by the artisanal fishery were *G. feliceps*, *P. ditchela*, *J. amblycephalus*, *L. equulus*, *P. maculatus*, *L. surinamensis* and *O. ruber*. Coincidentally the inshore areas of these estuaries also harbour abundant shrimps (Munga et al. 2013), thereby confirming the existing resource-use conflict. Therefore, in order to avoid this conflict in the estuaries of the bay, the stipulated measures in the management plan of minimum trawling distance of  $\geq 3$  nm offshore, closed trawling season, and the mandatory use of BRDs and Turtle Excluder Devices (TEDs) should be emphasised, in addition to continued prohibition of night trawling in order to achieve sustainable utilisation of fisheries resources. Continued monitoring of fish trawl bycatch quantities and species diversity is however, recommended for both estuaries so as to get a clearer spatio-temporal pattern for effective management.

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