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Propulsion-gear-based characterisation of artisanal fisheries in the Malindi-Ungwana Bay, Kenya and its use for fisheries management

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ABSTRACT

In Kenya, like other tropical countries, coastal artisanal fishery is multispecies, multigear and multifleet in nature with many management challenges. The Malindi-Ungwana Bay in particular, supports both the artisanal fishery and the semi-industrial bottom trawl shrimp fishery presenting a management challenge. Recent stock assessment surveys have identified catch composition of the semi-industrial bottom trawl fishery in the bay but artisanal catches remain barely described. This study describes, the artisanal fish catch composition (total number of species caught, sizes and trophic levels), and catch-per-unit-effort (CPUE) for each of the most popular propulsion-gear categories used in the bay. We make a case that the use of specific propulsion-gear categories can be dynamically managed to encourage the recovery of selected fish groups and thus support fisheries management. A total of 4 269 finfish belonging to 177 species and 66 families were sampled by the 5 most popular propulsion-gear categories between 2009 and 2011. The total number of species caught was highest for canoe-gillnet, *mashua*-gillnet and foot-seine net, and lowest for foot-handline and *mashua*-handline. Significant differences in catch composition existed between the different propulsion-gear categories. The CPUE was not significantly different between propulsion-gear, although this was on the average highest for canoe-gillnet and *mashua*-gillnet, and lowest for the foot-handline. The highest trophic level of 4.0 was recorded for *mashua*-gillnet and the lowest 3.4 and 3.2 for canoe-gillnet and foot-seine net respectively. The use of specific combinations of propulsion-gear categories, give an alternative approach in management recommendation of the coastal artisanal fisheries in the tropics, from the traditional gear-based management initiative. This study, singled out the *mashua*-gillnet, canoe-gillnet and foot-seine net as suitable units for monitoring the artisanal fisheries in Malindi-Ungwana Bay since *mashua*-gillnet lands the highest mean trophic level and largest sized individuals, and canoe-gillnet and foot-seine net land the highest number of species caught and smallest sized individuals.

1. Introduction

Sustainable management of coastal artisanal or small-scale fisheries in the tropics is challenging due to the multigear, multispecies and multifleet (propulsion) nature and the lack of adequate resources to conduct scientific studies, monitoring and enforcement (McClanahan and Mangi, 2004). Catch-per-unit-effort (CPUE) and species composition of catches are used to guide management but are difficult to establish due to the lack of long term and accurate artisanal fisheries data (McClanahan and Mangi, 2004; Marquez-Farias, 2005; Cinner et al., 2009; Kronen et al., 2012). Nevertheless 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). Therefore, artisanal fisheries has received increased attention from scientists and environmental managers for various ecological and socio-economic reasons, including user conflicts, habitat destruction and stock depletions. Furthermore, the current climate change phenomenon is an additional challenge to the management of reef-based fisheries as reef habitats are getting destroyed under unprecedented pressure (Cinner et al., 2009).

So far only a few studies in the tropics including Kenya, Madagascar and New Papua Guinea examined species selectivity by

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gear and recommended for gear-based artisanal fisheries management (McClanahan and Mangi, 2004; Mangi and Roberts, 2006; McClanahan and Cinner, 2008; Cinner et al., 2009; Davies et al., 2009). However, these studies did not address species selectivity by incorporating propulsion-gear combination and many studies have only dealt with species and size selectivity based on gillnet mesh sizes (MacLennan, 1992, 1995; Chopin and Arimoto, 1995; Stergiou and Erzini, 2002; Marquez-Farias, 2005; Matic-Skoko et al., 2011). Furthermore, artisanal fishing grounds in the tropics are remarkably heterogeneous, ecologically diverse and variably accessible depending on vessel or propulsion, gear and season, which makes it difficult to identify catch composition. In Kenya, such fishing habitats include lagoon and inshore areas, the reef itself, fishing grounds beyond the reef and deep waters (Hoorweg et al., 2008).

In the Malindi-Ungwana Bay, Kenya, artisanal fisheries is restricted to the inshore fishing grounds mostly less than 3 nautical miles (nm) due to the inability of the traditional propulsion types to access offshore fishing grounds. These inshore fishing grounds are also the main shallow water shrimp trawling grounds where user conflict between the artisanal and semi industrial shrimp trawl fisheries has been reported (Mwatha, 2005; Munga et al., 2012, 2013). Since the promulgation of the shrimp fishery management plan in 2011, conflicts between the two fishery types would be minimal once bottom trawling fully operates. Currently 1 to 2 trawlers instead of the proposed maximum of 4 have been operating in the bay after lifting of the trawling ban in July 2011. Artisanal fleet in the bay consists of a variety of traditional propulsion types including *mtumbwi, hori* and *dau* (here collectively referred to as canoes), *ngalawa* (outriggers pointed at both ends), *mashua* (bigger plankwood boats pointed at one end) to dinghies and surf boards (Fulanda et al., 2009, 2011). Fishing gear in use include traps (fixed and portable), spear guns, gill nets, seine nets, longlines, handlines, cast nets and recently the use of ring nets (McClanahan and Mangi, 2004; Fulanda et al., 2009, 2011). Approximately 3 500 artisanal fishers operate more than 600 traditional fishing vessels targeting both fish and shellfish species in the bay (Fulanda et al., 2011), with estimated landings of between 1 014 and 1 653 t annually (Munga et al., 2012). Most fishing activities take place between October and March during the dry Northeast Monsoon (NEM) season when the sea is warmer and calmer compared to the wet Southeast Monsoon (SEM) season (April to September) with cool and rough sea (McClanahan, 1988).

This is the first study to describe the Malindi-Ungwana Bay artisanal fish landings composition (species diversity, sizes, and trophic levels), and catch-per-unit-effort (CPUE) based on the most popular propulsion-gear categories. The study tests the following hypotheses: i) different propulsion-gear categories constitute different seasonal fish landing compositions and therefore, ii) different catch selectivity, iii) different trophic levels; and iv) different seasonal catch-per-unit-effort.

2. Materials and methods

2.1. Data collection

Shore-based catch assessments were conducted in 2009 (June, November and December), 2010 (March, June and September), and 2011 (March, July and September) in three major fishing areas: Malindi (39 assessments), Ngomeni (27 assessments) and Kipini (18 assessments) located along the 200 km long Malindi-Ungwana Bay (Fig. 1) totalling to 49 shore visits and 84 samples covering both the dry NEM and wet SEM seasons. 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. At the Tana River estuary, the bay is shallow with a wide continental shelf measuring 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 River estuary, the continental shelf is narrow, stretching between 3 and 5 nm offshore, where after depth rapidly increases to 40 m (Kitheka et al., 2005). At the landing sites, fish landings were examined from all fishers in the early morning for the night fishers and during the day for the day fishers. For large catches, total catch weight was measured using a weighing balance and a homogeneous mixture made before a sub-sample was randomly taken for individual fish length measurement and total weight measured for each species. For small catches, the total length for all individuals was measured and weighed by species. Fish species were identified using van der Est (1981), Smith and Heemstra (1998) and Lieske and Myers (1994). Total length (TL, cm) of individual fish was measured using a fixed marked ruler on a flat board. Gear type, propulsion type, number of fishers, active fishing time (h) excluding navigation time to and from the fishing grounds were also recorded. A total of 9 502 kg of fish was weighed during this study 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.

2.2. Data analyses

Catch-per-unit-effort (CPUE) by season was calculated for the most popular propulsion-gear categories used in the bay: canoe-gillnet, foot-seine net, foot-handline, *mashua*-gillnet and *mashua*-handline (Table 1). For each propulsion-gear category, totals of catch landed in a day were divided by the number of fishers. The average catch (kg/fisher), was divided by the active fishing time (h), and CPUE expressed in kg/fisher.h. Differences in CPUE and total expected number of species in each ten individuals sampled between propulsion-gear catagories with seasons were determined using 2-way ANOVA. The same test was used for differences in fish sizes (mean TL) and mean trophic level. Differences in sizes of individual fish species between propulsion-gear categories were tested by 1-way ANOVA, as number of individuals of most species were not always sufficiently high for both seasons. All the ANOVA tests were followed by a post hoc pair-wise comparison using the Tukey HSD test, and Levene's test was used for homoscedascity of the variances. Where necessary, data were appropriately Log(X+1) transformed. All parametric univariate tests were performed using STATISTICA v7. Fish species diversity by propulsion-gear category with seasons combined were analysed using rarefaction curves.

The individual fish species trophic levels were obtained from FishBase (Froese and Pauly, 2011; see annex). Trophic level estimates for each species were based on diet composition data compiled in FishBase where the trophic level of each fraction of the diet of fish was used to calculate the mean trophic level for the species. Since plants, macroalgae and detritus are defined as trophic level 1, the following fish trophic levels were used: herbivores as trophic level 2, omnivores as trophic level 3, and carnivores as trophic level 4. The mean trophic level of the catch by propulsion-gear category k was calculated as:

$$\overline{TL_k} = \sum_{i=1}^{m} Y_{ik} TL_i \Big/ \sum_{i=1}^{m} Y_{ik}$$

where Y_{ik} is the landings/catch of species i in propulsion-gear category k, TL_i is the trophic level of species i for m fish species

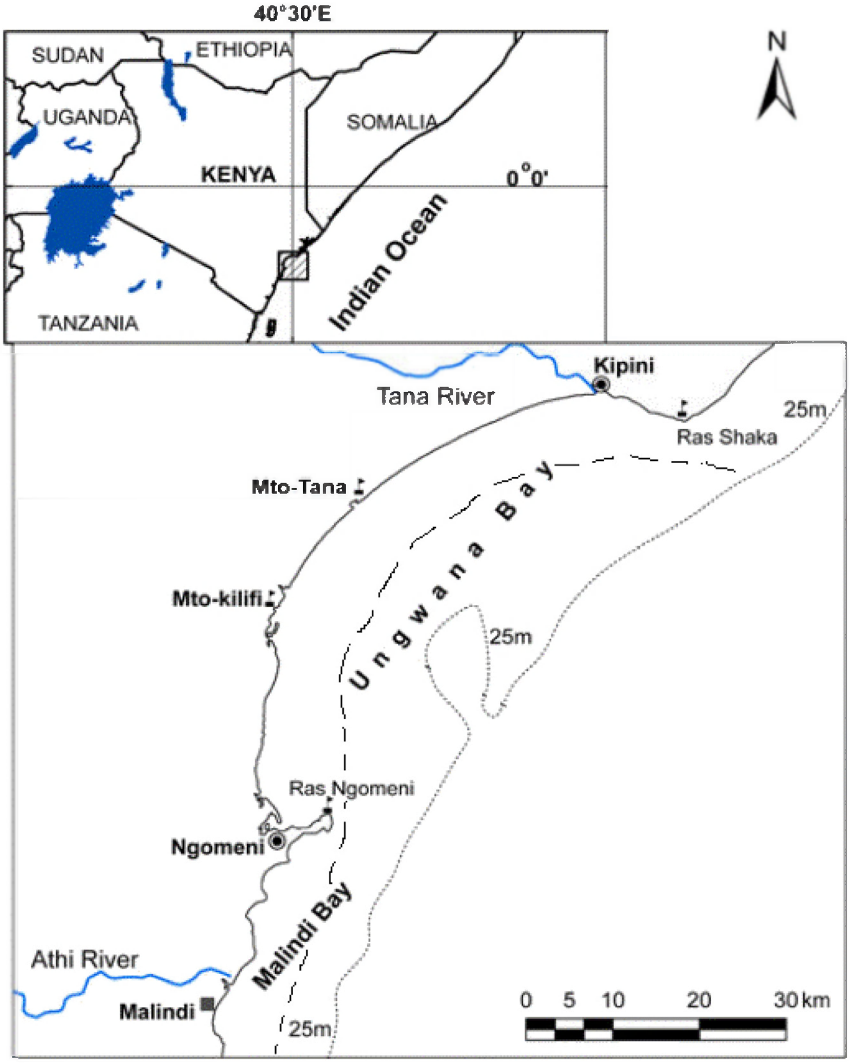

Fig. 1. Map of East African coast showing location of the study site: the Malindi-Ungwana Bay, Kenya and a demarcation of the 3 nm offshore artisanal fishing grounds (black dotted line, modified from Munga et al., 2012).

which was also used to calculate the standard error (SE) of the mean trophic level (Pauly et al., 2001).

Differences in multivariate species composition between propulsion-gear categories with seasons were visualised with non-metric Multidimensional Scaling (MDS) on the basis of Bray Curtis similarities between samples of standardised data. Two-way ANOSIM test was performed to determine the magnitude of seasonal differences in catch composition, and differences between the propulsion-gear categories. Species contributing most to the separation of catches between propulsion-gear categories with seasons were determined using a 2-way SIMPER analysis. These results of 2-way SIMPER analysis also identified the species selectivity by propulsion-gear category based on species abundance. This analysis indicated the average contribution of each species to

Table 1
Frequency of use (a) propulsion types, (b) gear types and (c) most popular propulsion-gear combinations sampled off the Malindi-Ungwana Bay, Kenya during the study period.

a			b			c		
Propulsion type	Count	% freq.	Gear type	Count	% freq.	Propulsion-gear type	Count	% freq.
Mashua	162	37.9	Gillnet	194	45.3	*Mashua*-gillnet	116	41
Foot	124	29	Handline	127	29.7	Foot-seine net	74	26
Canoe	63	14.8	Seine net	79	18.5	Canoe-gillnet	39	14
Surf board	46	10.8	Longline	19	4.4	*Mashua*-handline	33	12
Dinghy	25	5.9	Spear gun	4	0.9	Foot-handline	18	6
Outrigger	4	0.9	Basket trap	1	0.2	–	–	–
Motor boat	3	0.7	Cast net	1	0.2	–	–	–
–	–	–	Ring net	1	0.2	–	–	–

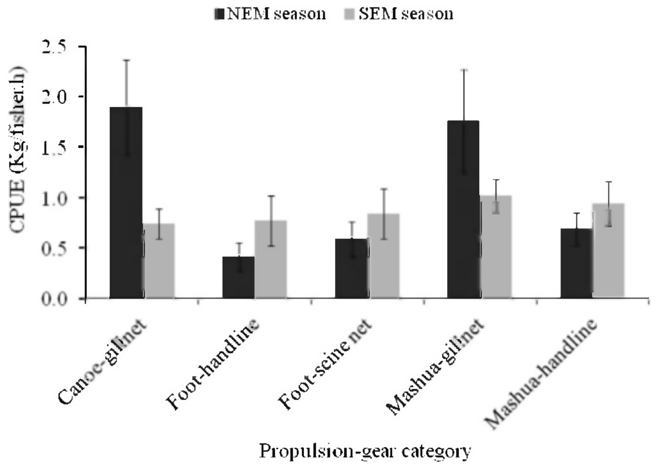

Fig. 2. Mean catch-per-unit-effort, CPUE (Kg/fisher. h ± SE) by the different propulsion-gear categories in the Northest Monsoon (NEM) and Southeast Monsoon (SEM) seasons for the Malindi-Ungwana Bay, Kenya artisanal fishery.

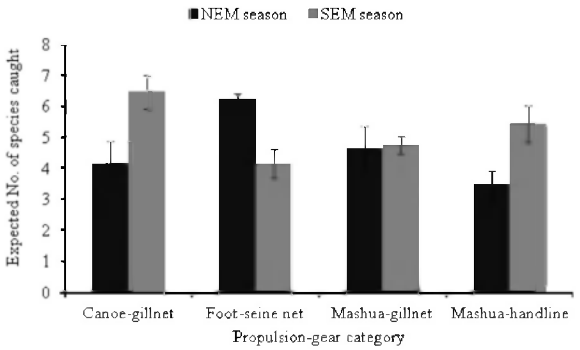

Fig. 4. Mean expected number ± SE of species caught in every ten samples (ES(10)) by the different propulsion-gear categories during the Northeast (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya. Data for foot-handline is not given due to the lowest number of individuals sampled.

the dissimilarity between groups of samples. All the multivariate analyses were performed using PRIMER v6 software (Clarke and Warwick, 2001).

3. Results

3.1. Seasonal catch-per-unit-effort by propulsion-gear category

A total of 7 propulsion types, 8 gear types and 5 most popular propulsion-gear categories were recorded in this study (Table 1). The propulsion types were in decreasing order of use the *mashua* (37.9%), by foot or no vessel (29.0%), and canoes (14.8%), whereas gillnets (45.3%), handlines (29.7%) and seine nets (18.5%) represented the most popular fishing gear. The *mashua*-gillnet (41%) was the most popular propulsion-gear category followed by the foot-seine net (26%). The canoe-gillnet (14%), *mashua*-handline (12%) and foot-handline (6%) followed in that order. The active fishing time excluding navigation time to and from the fishing grounds by propulsion-gear category was longest for *mashua*-handline (11.4 h/day) and lowest for the foot-seine net (3.2 h/day) and foot-handline (3.7 h/day). For the *mashua*-gillnet and canoe-gillnet, mean active fishing time at sea was 6.5 and 5.2 h/day respectively. The highest CPUEs were recorded in canoe-gillnet and *mashua*-gillnet, and the lowest recorded in foot-handline and foot-seine net, however with no significant differences observed neither between propulsion-gear categories nor between the seasons ($p > 0.05$; Fig. 2).

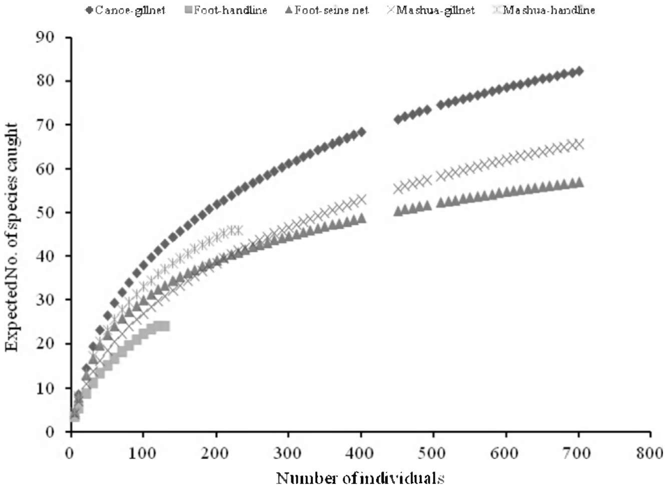

Fig. 3. Rarefaction curves indicating the expected total number of fish species caught by the different propulsion-gear categories with all seasons combined in the Malindi-Ungwana Bay, Kenya.

3.2. Fish species diversity, mean trophic levels and selectivity by propulsion-gear category

A total of 4 269 individuals belonging to 177 species in 66 families were sampled from the most popular propulsion-gear categories in the bay (see annex). Rarefaction curves based on the most popular propulsion-gear categories with seasons combined (Fig. 3), indicated that canoe-gillnet caught the highest expected number of fish species followed by the *mashua*-gillnet and foot seine net. The lowest expected number of species was associated with the foot-handline and *mashua*-handline. Excluding the foot-handline with the fewest samples, 2-way ANOVA indicated no significant difference in the exepected total number of species caught for every ten individuals sampled neither between the propulsion-gear categories nor between the seasons ($p > 0.05$ both cases; Fig. 4). The same test however, indicated a significant effect due to the interaction of propulsion-gear category with season (Df = 3; Err Df = 59; $F = 9.298$; $p < 0.001$).

The largest individuals were landed by the *mashua*-gillnet measuring mean TL of 56.1 cm, and foot-seine net landed the smallest individuals (17.9 cm; Fig. 5). The *mashua*-handline landed

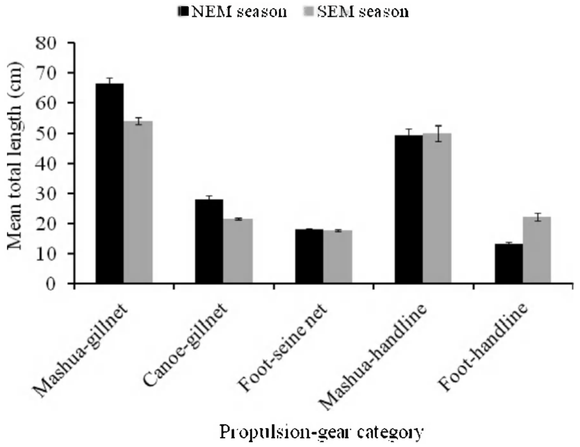

Fig. 5. Mean total length (TL cm ± SE) of finfish landings by the different propulsion-gear categories in the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya during the study period.

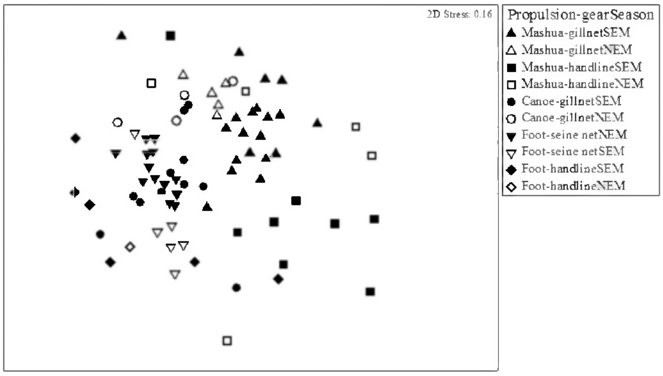

Fig. 6. Non-metric MDS plot showing the similarities in relative composition (%) of artisanal finfish landings by the different propulsion-gear categories with seasons sampled in the Malindi-Ungwana Bay, Kenya during the study period.

a mean size of 49.7 cm, canoe-gillnet (23.1 cm), and foot-handline (20.7 cm). Results of 2-way ANOVA indicated no significant difference in mean TL of fish landings between the seasons ($p > 0.05$), but a significant difference between the propulsion-gear categories (Df = 4; Err Df = 4 914; $F = 1\ 124.200$; $p = 0.000$). The same test indicated a significant effect due to the season-propulsion-gear category interaction (Df = 4; Err Df = 4 914; $F = 27.500$; $p = 0.000$). Results of post hoc pair-wise comparison confirmed the mean TL of fish from canoe-gillnet, foot-seine net and foot-handline for both seasons, were indeed significantly smaller compared to those of *mashua*-gillnet and *mashua*-handline ($p < 0.05$). Pelagic fish landings was higher in composition in *mashua*-gillnets (57.3%) than demersals (42.7%). In *mashua*-handline demersals made 78.7% in composition, much higher than pelagics at 21.3%. The canoe-gillnet had 62.4% composition of demersals and 37.6% pelagics. Demersal composition in foot-handline was 94.1% and only 5.9% was composed of pelagics. Demersal composition was also higher in foot-seine net (54.1%) than pelagics (45.9%).

The non-metric MDS (Fig. 6) showed distinct composition of fish landings by propulsion-gear category in different seasons. Two-way ANOSIM combining propulsion-gear category with season indicated significant difference in fish landing compositions between the propulsion-gear categories and to a lesser extent between the seasons ($R = 0.510$; $p = 0.001$ and $R = 0.194$; $p = 0.036$ respectively). The difference in fish landings composition between the different propulsion-gear categories were confirmed with the results of pair-wise comparison tests (Table 2: $p < 0.05$). Results of 2-way SIMPER analysis indicated a total of 14 most abundant fish species that caused the variation in species composition between the propulsion-gear categories (Fig. 7). The *mashua*-gillnet mostly landed *Lobotes surinamensis, Psettodes erumei, Galeichthys feliceps* and *Carcharhinus melanopterus*. *Lethrinus lentjan* and *Acanthurus xanthopterus* were mostly landed by the *mashua*-handline. The canoe-gillnet mostly landed *G. feliceps*, *Thryssa vitrirostris* and *Otolithes ruber*. *Pellona ditchela, Lutjanus fulviflamma, Siganus sutor, Leptoscarus vaigeinsis* and *Hilsa kelee* were mostly landed by the foot-seine net, whereas the foot-handline mostly landed *L. fulviflamma* and *Acanthopagrus berda*. Generally there was an average dissimilarity of 86.4% of fish landing composition between the dry NEM and wet SEM seasons, and the abundance of the 14 fish species also varied between the seasons with the majority of these species being more abundant during the NEM season (Table 3).

Table 2
Results of pair-wise tests showing significant differences between propulsion-gear category comparisons in catch composition in the Malindi-Ungwana Bay, Kenya during the study period.

Vessel-gear category	R Statistic	p Value	Possible Permutations	Actual Permutations	Number ≥ Observed
Mashua-gillnet, *Mashua*-handline	0.481	***0.001***	Very large	999	0
Mashua-gillnet, Canoe-gillnet	0.393	***0.001***	Very large	999	0
Mashua-gillnet, Foot-seine net	0.625	***0.001***	Very large	999	0
Mashua-gillnet, Foot-handline	0.553	***0.001***	33251400	999	0
Mashua-handline, Canoe-gillnet	0.492	***0.001***	9523332	999	0
Mashua-handline, Foot-seine net	0.731	***0.001***	25729704	999	0
Mashua-handline, Foot-handline	0.281	***0.006***	168168	999	5
Canoe-gillnet, Foot-seine net	0.526	***0.001***	29454880	999	0
Canoe-gillnet, Foot-handline	0.39	***0.001***	433160	999	0
Foot-seine net, Foot-handline	0.784	***0.001***	258720	999	0

(bold and italic are significant, $p < 0.05$).

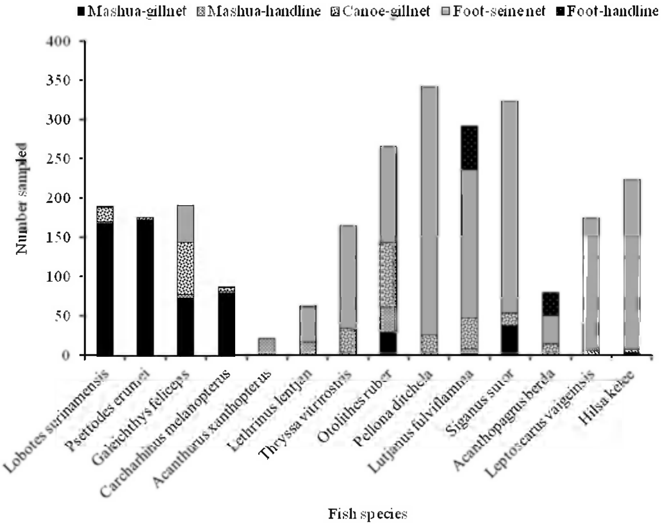

Fig. 7. Selectivity by propulsion-gear for finfish species responsible for differences between the different propulsion-gear categories identified by SIMPER in Malindi-Ungwana Bay, Kenya during the study period.

Table 3
SIMPER results showing seasonal (Northeast, NEM and Southeast, SEM) composition (%) of the most abundant fish species that caused the variation in species composition between the different propulsion-gear categories in the Malindi-Ungwana Bay fishery, Kenya.

Species	SEM season	NEM season		
	Average abundance	Average abundance	Average dissimilarity	Per cent contribution
Galeichthys feliceps	2.59	9.46	8.63	9.98
Lobotes surinamensis	6.77	8.12	6.18	7.15
Psettodes erumei	9.53	0.05	4.34	5.02
Otolithes ruber	1.50	7.91	3.55	4.11
Thryssa vitrirostris	0.39	6.91	3.23	3.74
Lutjanus fulviflamma	5.90	7.88	3.22	3.73
Pellona ditchela	1.23	8.93	3.04	3.51
Siganus sutor	3.72	3.29	2.52	2.92
Hilsa kelee	2.35	0.32	2.50	2.90
Lethrinus lentjan	1.54	4.04	1.92	2.22
Carcharhinus melanopterus	3.75	0.49	1.86	2.16
Acanthurus xanthopterus	0.45	4.13	1.69	1.96
Leptoscarus vaigiensis	0.45	3.67	1.13	1.30
Acanthopagrus berda	2.45	0.00	0.82	0.95

L. fulviflamma was landed by the canoe-gillnet, foot-seine net and foot-handline at mean TL of 18.49 ± 0.67 cm, 15.20 ± 0.26 cm and 15.08 ± 0.56 cm respectively. There was significant difference in mean TL between the propulsion-gear categories (Df = 2; Err Df = 281; $F = 13.073$; $p < 0.001$), and results of pair-wise comparison confirmed that significantly larger *L. fulviflamma* individuals were indeed landed by the canoe-gillnet. Length frequencies of this species for these propulsion-gear categories indicated size selectivity of canoe-gillnet for larger *L. fulviflamma* individuals of 14 cm and above (Fig. 8a). *G. feliceps* was landed by the *mashua*-gillnet, canoe-gillnet and foot-seine net at mean TL of 59.49 ± 1.79 cm, 33.36 ± 1.18 cm and 21.64 ± 0.83 cm respectively. The mean TL of *G. feliceps* individuals differed significantly between the propulsion-gear categories (Df = 2; Err Df = 183; $F = 190$; $p = 0.000$), and results of post hoc pair-wise comparison confirmed this difference ($p < 0.05$). The length frequency (Fig. 8b) showed *mashua*-gillnet selectivity for the largest individuals of this species. The canoe-gillnet and foot-seine net on the other hand, both landed *O. ruber* measuring mean TL of 25.72 ± 0.52 cm and 21.44 ± 0.47 cm respectively. The mean TL were significantly different between these propulsion-gear categories (Df = 1; Err Df = 203; $F = 36.103$; $p = 0.000$). A distinct size selectivity was observed in canoe-gillnet for more larger *O. ruber* individuals (Fig. 8c).

The *mashua*-gillnet, *mashua*-handline and foot-handline recorded higher mean trophic levels during the wet SEM season, and the canoe-gillnet and foot-seine net recorded higher mean trophic levels during the dry NEM season (Fig. 9). During the SEM season, the *mashua*-gillnet recorded the highest mean trophic level (4.0 ± 0.08) of fish landings and the foot-seine net and canoe-gillnet recorded the lowest mean trophic level of 3.2 ± 0.08 and 3.4 ± 0.07 during the SEM season respectively. There was a significant difference in mean trophic levels of fish landings between the propulsion-gear categories (Df = 4; Err Df = 4 920; $F = 146.470$; $p = 0.000$) but not between the seasons ($p > 0.05$). There was also a significant effect due to propulsion-gear category with season interaction (Df = 4; Err Df = 4 920; $F = 18.570$; $p = 0.000$). Results of post hoc pair-wise comparison confirmed mean trophic levels during the SEM season from both the foot-seine net and canoe-gillnet significantly differed from those of the NEM season, and from the rest of propulsion-gear categories during both the season ($p < 0.05$).

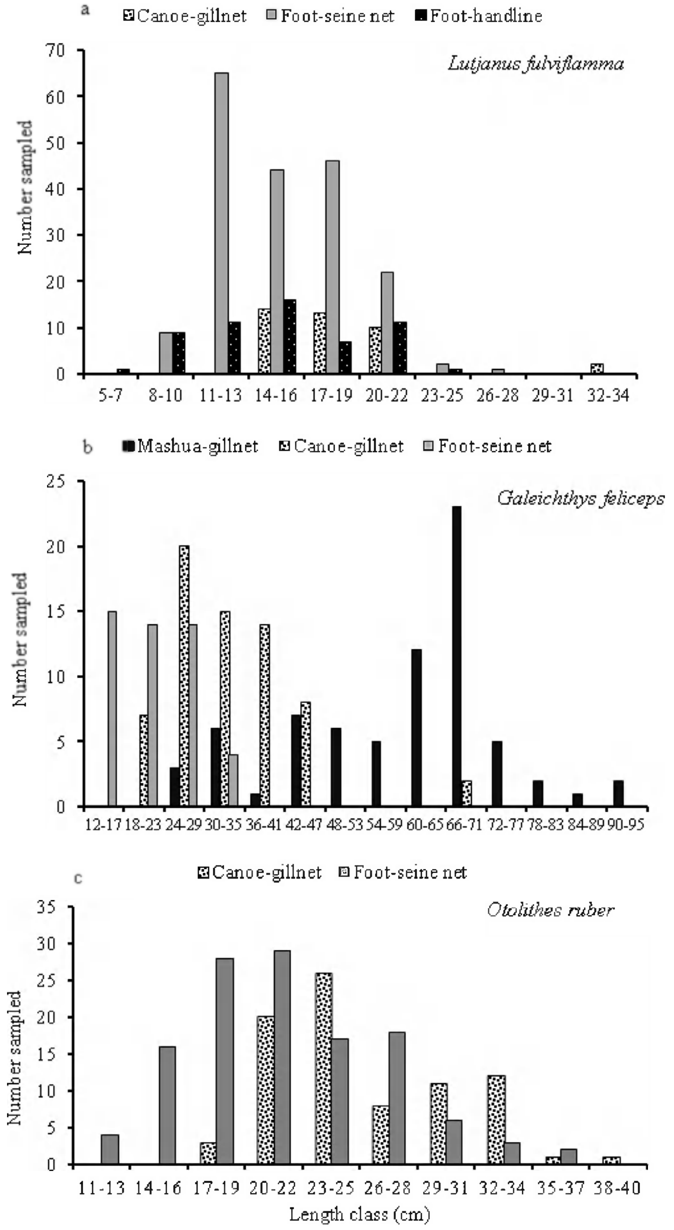

Fig. 8. Comparison of size distributions of *Lutjanus fulviflamma* landed by a) canoe-gillnet, foot-seine net and foot-handline; *Galeichthys feliceps* landed by b) *mashua*-gillnet, canoe-gillnet and foot-seine net; and *Otolithes ruber* landed by c) canoe-gillnet and foot-seine net in the Malindi-Ungwana Bay, Kenya during the study period.

4. Discussion

The 177 fish species from a total of 4 269 individuals sampled in this study is typical of a multigear tropical artisanal fishery that is non-selective, as evidenced by the high diversity of species landed. Even though fishers have preferences for certain fish species, any available fish will be retained and only a few are considered inedible (Mangi and Roberts, 2006; Davies et al., 2009). Higher numbers of fish species caught by the canoe-gillnets and *mashua*-gillnets in this study, might have been attributed to the use of nets of various mesh sizes ranging between less than 2.5 inches to over 10 inches (Government of Kenya, 2010). Canoes and *mashua* boats also have the advantage of accessing various fishing grounds with a comparative longer duration of sea time than fishers using foot as a means of propulsion. Apart from using undersized mesh sizes, different types of gillnets such as monofilament are illegal by law (Government of Kenya, 1991). Monofilaments are non-

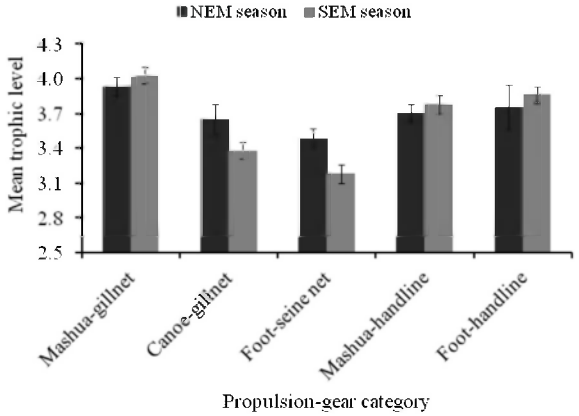

Fig. 9. Mean trophic levels (±SE) of artisanal finfish landings by the different propulsion-gear category in the Malindi-Ungwana Bay, Kenya during the study period.

biodegradable and would continue catching fish as 'ghost gear' incase of loss of such fishing nets. In this study, the smallest sized fish were associated with the foot-seine nets, and the largest fish were landed by the *mashua*-gillnet. The use of foot-seine nets is restricted in shallow depths coupled with use of undersized mesh sizes of less than the legalised 2.5 inches. Contrary, the *mashua*-gillnets are associated with relatively offshore fishing with bigger mesh sizes of more than 6 inches (Government of Kenya, 1991). Beach seine, a type of seine net, has been associated with capture of the smallest sized and immature individuals (McClanahan and Mangi, 2004; Davies et al., 2009). In this study, beach seines were not included since they are illegal by law due to their destructive nature both to the environment and the associated loss of biodiversity. Foot-seine net should be controlled so as to minimise the fishing pressure in nearshore critical habitats that are likely to be nursery grounds of fish species.

On the other hand, the *mashua*-handlines and foot-handlines were associated with the lowest numbers of fish species caught. This is a clear indication of species selectivity by these propulsion-gear categories and are therefore potentially more suitable in sustaining the artisanal fisheries in Malindi-Ungwana Bay if they are well managed. Also the fishing grounds for these propulsion-gears influences catch composition. *Mashua*-handlines and *mashua*-gillnets are mostly used by the commercial artisanal fishers capable of accessing relatively deeper and further offshore fishing grounds using the larger *mashua* boats that are propelled either by sails or outboard engines, and capable of staying at sea for a few hours to several days (pers. comm.). In this study, specific size selectivity was manifested in canoe-gillnets for larger *L. fulviflamma* and *Otolithes ruber* individuals, and in *mashua*-gillnets for larger *G. feliceps* individuals. Although there was no significant difference between propulsion-gears and seasons for total number of species expected in every ten individuals sampled, differences were outstanding in catch-per-unit-effort (CPUE), fish sizes and mean trophic levels between the different propulsion-gear categories. In this study relatively higher CPUE was associated with the *mashua*-gillnet and canoe-gillnet and relatively lower for foot-handline and foot-seine net, which is comparable with findings by Teh et al. (2009) in a survey of CPUEs in Fiji's inshore artisanal fisheries, where gillnets had the highest CPUE of 19–32 kg/set, and much lower for handlines with CPUE of 1.4 ± 0.3 kg/fisher.h.

Seasonal differences in catch composition between the propulsion-gears was likely attributed to the variability and accessibility of the fishing grounds in different seasons of the year, and fishing frequency of fishers. During the dry Northeast Monsoon (NEM) season, both the *mashua* and canoes are capable of accessing relatively further offshore fishing grounds as the sea is calm and therefore navigation and fishing operations using gillnets and handlines is possible, coupled with longer duration at sea. On the other hand, during the wet Southeast Monsoon (SEM) season, the seas are rough making offshore navigation and fishing impossible. During this season, fishers use specific fishing grounds that are protected from the strong waves, and normally sea time during this season is reduced. However, frequency of fishing is reportedly higher for fishers using the bigger *mashua* boats than those using foot or smaller canoes during this unfavorable weather (Hoorweg et al., 2008). The seasonal differences in catch composition are also species specific in that some species became more abundant in certain seasons of the year (Table 3).

Mean trophic levels indicate the status of resource exploitation. The fish landings of *mashua*-gillnet associated with relatively larger wooden boats and nets (either set or drift gillnets) exploited fish species at the highest trophic level of 4.0. Such fish species were mostly large carnivorous pelagics. The canoe-gillnets and foot-seine nets on the other hand landed the lowest mean trophic levels of 3.4 and 3.2 respectively. These were fish species lower in the food chain and mostly demersals. Over-exploitation of reef fish species has resulted to fish landings of lower mean trophic levels. Davies et al. (2009) reported a lowest mean trophic level of 2.6 for spear gun, and a highest of 3.7 for longline in the south-west Madagascar inshore artisanal fisheries. Other inshore fisheries have recorded much lower mean trophic levels than the one reported for Malindi-Ungwana Bay, Kenya in this study. For example, the southern Kenya artisanal reef fishery recorded a mean trophic level of between 2.6 and 2.9 (McClanahan and Mangi, 2004), south-west Madagascar artisanal fishery with 2.6–3.4 (Davies et al., 2009), and the Papua New Guinea artisanal fishery with 2.8–3.7 (McClanahan and Cinner, 2008). These values therefore, are a clear indication that, in comparison with the other artisanal fisheries, the Malindi-Ungwana Bay fishery could be described as relatively less exploited. The relatively higher mean trophic level values calculated for the different propulsion-gear categories in this study could be monitored overtime so as to discourage fishing down the web as described by Pauly et al. (2001). Analysis of the mean trophic levels however, does not take into consideration of ontogenetic diet shifts of the fish species, and therefore these present values are likely to change with better techniques.

There is worldwide lack of reliable data on the type, dimension and quantity of fishing gear needed for accurate assessment of fishing effort in tropical coastal artisanal fisheries. Even if they exist, they are unsystematically monitored and recorded making detailed analysis difficult (Farrugio et al., 1993; Colloca et al., 2004; Battaglia et al., 2010). The quantification of fishing effort is complex given the high diversity of propulsion or vessel and fishing gear types characterising the artisanal fisheries (Staglicic et al., 2011). Artisanal fisheries assessment in the past, has been mainly based on the number of boats and fishers, and this has a limitation for the evaluation of the actual fishing pressure on the resources (Salas et al., 2007). The categorisation by propulsion-gear in this study, therefore provides a more systematic assessment of the artisanal fisheries and generates more reliable information for accurate decision making.

Typical of a tropical artisanal fishery, results in this current study have shown that both the propulsion types and fishing gear were indeed diverse and targeted multispecies. As opposed to the bottom shrimp trawl fishery associated with high discarding of bycatch in the Malindi-Ungwana Bay (Munga et al., 2013), the artisanal fishery in the bay and generally in the developing tropical countries, discarding of bycatch is not common especially with the legal fishing gear investigated in this study (Mangi and Roberts, 2006). The different propulsion types encountered in the bay were varied in size with the *mashua* boat being the biggest (10 m long) and dug-out canoe the smallest (4 m long). Locomotion aids for these propulsion types also varied including the use of mechanical inboard and outboard engines, and wind driven sails, to use of manually operated oars and poles. Several characteristics were also associated with the various fishing gear including diversity in make and mesh sizes, net length and width. Also line fishing varied in type, length, hook size and number in addition to differences in bait types. All these variables have the potential of affecting catch composition, but this current study did not take into consideration of such details given the complexity and diversity associated with artisanal fishery.

In conclusion, the multispecies, multigear and multifleet characteristics of tropical artisanal fishery make it difficult to manage fisheries resources. Therefore, there is need to identify combination of fishing units such as propulsion-gear categories to generate more reliable indices that can be used to provide management recommendations instead of the traditional gear-based management strategy. This study therefore, singles out the *mashua*-gillnet, canoe-gillnet and foot-seine net as suitable units for monitoring of the artisanal fisheries in Malindi-Ungwana Bay due to landing of fish of highest mean trophic level and largest sized individuals for the *mashua*-gillnet, and landing of highest number of fish species of smallest sized individuals for the foot-seine net and canoe-gillnet. While total annual artisanal landings have been reported to be higher in the NEM season than SEM season (Ochiewo, 2004), the catch-per-unit-effort may not necessarily follow the same trend as observed in this study.

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Annex

Summary of fish species sampled from shore-based catch assessments in the Malindi-Ungwana Bay, Kenya during the study period.

Species	Family	Number sampled (n)	Ecological group	Trophic level
Pellona ditchela	Clupeidae	337	Pelagic	4.0
Otolithes ruber	Sciaenidae	264	Pelagic	3.6
Lutjanus fulviflamma	Lutjanidae	260	Demersal	3.8
Siganus sutor	Siganidae	193	Demersal	2.0
Lobotes surinamensis	Lobotidae	187	Pelagic	4.0
Galeichthys feliceps	Ariidae	183	Demersal	3.5
Psettodes erumei	Psettodidae	170	Demersal	4.4
Thryssa vitrirostris	Engraulidae	163	Pelagic	3.3
Gerres oyena	Gerreidae	156	Demersal	3.1
Leptoscarus vaigiensis	Scaridae	141	Demersal	2.3
Sphyrna zygaena	Sphyrnidae	127	Pelagic	4.5
Leiognathus equulus	Leiognathidae	127	Demersal	3.0
Hilsa kelee	Clupeidae	118	Pelagic	3.3
Johnius amblycephalus	Sciaenidae	98	Demersal	4.1
Carcharhinus melanopterus	Carcharhinidae	86	Pelagic	3.9
Carangoides armatus	Carangidae	86	Pelagic	4.3
Caranx ignobilis	Carangidae	80	Pelagic	4.2
Lethrinus lentjan	Lethrinidae	65	Demersal	4.2
Terapon jarbua	Terapontidae	63	Demersal	3.9
Pomadasys maculatus	Haemulidae	59	Demersal	4.0
Leiognathus daura	Leiognathidae	59	Demersal	3.0
Hemiramphus far	Hemiramphidae	58	Pelagic	2.9
Scomberoides tol	Scombridae	56	Pelagic	4.4
Scomberoides commersonnianus	Scombridae	51	Pelagic	4.5
Gerres filamentosus	Gerreidae	48	Demersal	3.3
Johnius dussumieri	Sciaenidae	39	Demersal	4.1
Tylosurus acus	Trichiuridae	39	Pelagic	4.5
Lethrinus harak	Lethrinidae	36	Demersal	3.5
Trichiurus lepturus	Trichiuri	36	Pelagic	4.5
Drepane punctata	Drepanidae	32	Demersal	3.3
Sphyrna lewini	Sphyrnidae	32	Pelagic	4.1
Photopectoralis bindus	Leiognathidae	30	Demersal	2.5
Thryssa malabarica	Engraulidae	30	Pelagic	3.3
Valamugil seheli	Mugilidae	30	Pelagic	2.3
Acanthopagrus berda	Sparidae	29	Demersal	2.9
Lethrinus nebulosus	Lethrinidae	22	Demersal	3.3
Acanthurus xanthopterus	Acanthuridae	21	Demersal	2.9
Sillago sihama	Sillaginidae	21	Demersal	3.4
Siganus canaliculatus	Siganidae	20	Demersal	2.8
Plotosus lineatus	Plotosidae	20	Demersal	3.5
Lutjanus argentimaculatus	Lutjanidae	19	Demersal	3.6
Lethrinus microdon	Lethrinidae	18	Demersal	3.8
Epinephelus malabaricus	Serranidae	16	Demersal	3.8
Caranx sexfasciatus	Carangidae	16	Pelagic	4.5
Polydactylus plebeius	Polynemidae	16	Demersal	3.6
Upeneus vittatus	Mullidae	16	Demersal	3.5
Chirocentrus dorab	Chirocentridae	15	Pelagic	4.5
Rastrelliger kanagurta	Scombridae	15	Pelagic	3.2
Elops saurus	Elopidae	14	Pelagic	4.0
Lutjanus sanguineus	Lutjanidae	13	Demersal	4.5
Pelates quadrilineatus	Terapontidae	12	Demersal	
Thunnus tonggol	Scombridae	11	Pelagic	4.5
Sphyraena putnamae	Sphyraenidae	11	Pelagic	4.5
Upeneus sulphureus	Mullidae	11	Demersal	3.2
Pomadasys commersonnii	Haemulidae	10	Demersal	3.5
Netuma thalassina	Ariidae	10	Demersal	3.1
Mugil cephalus	Mugilidae	10	Pelagic	2.1
Bothus mancus	Bothidae	9	Demersal	4.4
Trachinotus blochii	Carangidae	9	Pelagic	3.7
Epinephelus tauvina	Serranidae	9	Demersal	4.1
Plectorhinchus gaterinus	Haemulidae	9	Demersal	4.0
Mulloidichthys vanicolensis	Mullidae	9	Demersal	3.6
Carangoides oblongus	Carangidae	9	Pelagic	4.2
Saurida undosquamis	Synodontidae	8	Demersal	4.5
Euthynnus affinis	Scombridae	8	Pelagic	4.5
Gnathanodon speciosus	Carangidae	7	Pelagic	3.8
Caranx heberi	Carangidae	7	Pelagic	3.7
Plectorhinchus pictus	Haemulidae	7	Demersal	3.5
Drepane longimana	Drepanidae	7	Demersal	3.5
Pempheris oualensis	Pempheridae	7	Demersal	3.5
Albula vulpes	Albulidae	6	Pelagic	3.0
Himantura uarnak	Dasyatidae	6	Demersal	3.6
Muraenesox cinereus	Muraenesocidae	6	Demersal	4.1
Triaenodon obesus	Carcharhinidae	6	Pelagic	4.2
Monotaxis grandoculis	Lethrinidae	6	Demersal	3.2
Hypoatherina temminckii	Atherinidae	6	Demersal	3.4
Monodactylus argenteus	Monodactylidae	6	Pelagic	3.0
Chanos chanos	Chanidae	6	Pelagic	2.0
Coryphaena hippurus	Coryphaenidae	5	Pelagic	4.4
Chlorurus sordidus	Scaridae	5	Demersal	2.0
Plectorhinchus schotaf	Haemulidae	5	Demersal	3.8
Tylosurus crocodilus	Belonidae	5	Pelagic	4.5
Secutor insidiator	Leiognathidae	5	Demersal	2.8
Plectorhinchus playfairi	Haemulidae	5	Demersal	3.3
Conger cinereus	Congridae	4	Demersal	4.4
Carcharhinus sp.	Carcharhinidae	4	Pelagic	3.9
Carcharhinus ablimarginatus	Carcharhinidae	4	Pelagic	3.9
Thunnus albacares	Scombridae	4	Pelagic	4.3
Gymnothorax elegans	Muraenidae	4	Demersal	4.0
Lethrinus miniatus	Lethrinidae	4	Demersal	3.5
Paraplagusia bilineata	Cynoglossidae	4	Demersal	3.5
Monodactylus falciformis	Monodactylidae	4	Demersal	3.5
Sphyraena jello	Sphyraenidae	4	Demersal	4.5
Lutjanus kasmira	Lutjanidae	4	Demersal	3.6
Leiognathus lineolatus	Leiognathidae	4	Demersal	3.5
Raja miraletus	Rajidae	3	Demersal	3.8
Rhizoprionodon acutus	Carcharhinidae	3	Pelagic	4.3
Sphyrna sp.	Sphyrnidae	3	Pelagic	4.5
Lichia amia	Carangidae	3	Pelagic	4.5
Muraenichthys schultzei	Ophichthidae	3	Demersal	3.5
Platax orbicularis	Ephippidae	3	Demersal	3.3
Aprion virescens	Lutjanidae	3	Demersal	4.0
Macolor niger	Lutjanidae	3	Demersal	4.0
Epinephelus coioides	Serranidae	3	Demersal	3.9
Caranx melampygus	Carangidae	3	Pelagic	4.5
Lutjanus gibbus	Lutjanidae	3	Demersal	4.1
Pomadasys sp.	Haemulidae	3	Demersal	4.0
	Scombridae	3	Pelagic	4.2

(continued on next page)

(*continued*)

Species	Family	Number sampled (*n*)	Ecological group	Trophic level
Scomberomorus plurilineatus				
Umbrina ronchus	Sciaenidae	3	Demersal	3.4
Thysanophrys chiltonae	Platycephalidae	3	Demersal	3.8
Arius africanus	Ariidae	3	Pelagic	3.8
Carangoides ferdau	Carangidae	3	Pelagic	4.5
Alectis indica	Carangidae	3	Pelagic	4.1
Platycephalus indicus	Platycephalidae	3	Demersal	3.6
Liza macrolepis/ Chelon macrolepis	Mugilidae	3	Demersal	2.6
Sphyraena barracuda	Sphyraenidae	2	Demersal	4.5
Sphyrna mokarran	Sphyrnidae	2	Pelagic	4.3
Scomberomorus guttatus	Scombridae	2	Pelagic	4.3
Acanthocybium Solandri	Scombridae	2	Pelagic	4.4
Manta birostris	Myliobatidae	2	Demersal	3.5
Sphyraena flavicauda	Sphyraenidae	2	Pelagic	3.8
Kyphosus vaigiensis	Kyphosidae	2	Pelagic	2.0
Carangoides fulvoguttatus	Carangidae	2	Pelagic	4.4
Cheilio inermis	Labridae	2	Demersal	4.0
Epinephelus fuscoguttatus	Serranidae	2	Demersal	4.1
Albula glossodonta	Albulidae	2	Pelagic	3.6
Stolephorus commersonnii	Engraulidae	2	Pelagic	3.1
Scomberoides sp.	Scombridae	2	Pelagic	4.5
Cheilinus trilobatus	Labridae	2	Demersal	3.5
Apogon sp.	Apogonidae	2	Demersal	4.0
Pomadasys olivaceus	Haemulidae	1	Demersal	2.6
Priacanthus hamrur	Priacanthidae	1	Demersal	3.6
Parupeneus indicus	Mullidae	1	Demersal	3.5
Holohalaelurus regani	Scyliorhinidae	1	Demersal	4.2
Himantura sp.	Dasyatidae	1	Demersal	3.6
Auxis thazard	Scombridae	1	Pelagic	4.3
Istiophorus sp.	Istiophoridae	1	Pelagic	3.5
Remora remora	Echeneidae	1	Demersal	3.1
Tetrapturus angustirostris	Istiophoridae	1	Pelagic	4.5
Synodus indicus	Synodontidae	1	Demersal	4.2
Plectorhinchus gibbosus	Haemulidae	1	Demersal	3.6
Rhynchobatus djiddensis	Rhinobatidae	1	Demersal	3.6
Echidna nebulosa	Muraenidae	1	Demersal	4.0
Epinephelus chlorostigma	Serranidae	1	Demersal	4.0
Gymnomuraena zebra	Muraenidae	1	Demersal	3.4
Lethrinus mahsena	Lethrinidae	1	Demersal	3.4
Lutjanus bohar	Lutjanidae	1	Demersal	4.1
Bodianus perditio	Labridae	1	Demersal	3.5
Cirrhitichthys oxycephalus	Cirrhitidae	1	Demersal	4.0
Lethrinus sp.	Lethrinidae	1	Demersal	3.5
Stegostoma fasciatum	Stegostomatidae	1	Pelagic	3.1
Lutjanus rivulatus	Lutjanidae	1	Demersal	4.1
Lutjanus sebae	Lutjanidae	1	Demersal	4.3
Mugil sp.	Mugilidae	1	Pelagic	2.1
Caranx sp.	Carangidae	1	Pelagic	4.2
Epinephelus fasciatus	Serranidae	1	Demersal	3.7
Kyphosus cinerascens	Kyphosidae	1	Demersal	2.3
Myripristis murdjan	Holocentridae	1	Demersal	3.3
Carcharhinus leucas	Carcharhinidae	1	Pelagic	4.3
Plectorhinchus flavomaculatus	Haemulidae	1	Demersal	4.0
Leiognathus sp.	Leiognathidae	1	Demersal	3.0
Sardinella gibbosa	Clupeidae	1	Pelagic	2.9
Upeneus taeniopterus	Mullidae	1	Demersal	3.5
Diagramma pictum	Haemulidae	1	Demersal	3.5
Synaptura commersonnii	Soleidae	1	Demersal	3.5
Fistularia petimba	Fistulariidae	1	Demersal	4.5
Alectis ciliaris	Carangidae	1	Pelagic	3.8
Calotomus spinidens	Scaridae	1	Demersal	2.0
Upeneus tragula	Mullidae	1	Demersal	3.6
Siganus stellatus	Siganidae	1	Demersal	2.7
Acanthopagrus sp.	Sparidae	1	Demersal	2.9
Polydactylus sextarius	Polynemidae	1	Demersal	3.8
Pomadasys argenteus	Haemulidae	1	Demersal	3.4
Lutjanus fulvus	Lutjanidae	1	Demersal	4.1
Naso brevirostris	Acanthuridae	1	Demersal	2.2
Leiognathus fasciatus	Leiognathidae	1	Demersal	3.3
Cephalopholis argus	Serranidae	1	Demersal	4.5
Total		4 269		

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