Western Indian Ocean JOURNAL OF Marine Science

Volume 18 | Issue 1 | Jan – Jun 2019 | ISSN: 0856-860X

Chief Editor José Paula

Western Indian Ocean JOURNAL OF Marine Science

Chief Editor **José Paula** | Faculty of Sciences of University of Lisbon, Portugal

Copy Editor **Timothy Andrew**

Published biannually

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ISSN 0856-860X

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Hook size selectivity in the artisanal handline fishery of Shimoni fishing area, south coast, Kenya

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Abstract
Selectivity of five handline fishing hook sizes was determined following Holt's 1963 model using data that was collected during January to June, 2016. A total of 966 fish specimens comprising of 65 species belonging to 23 families were sampled. Fish abundance was low for large sized hooks while catch rate was higher. Species diversity was higher during the northeast monsoon season and at the study sites of Mpunguti and Nyuli. However, species diversity decreased with increase in hook size. All hook sizes had a higher selection for mature *Lethrinus borbonicus* while hook size No. 8 selected immature *Lethrinus lentjan*. Hook sizes No. 9 and 10 selected mature *L. lentjan* and *Lethrinus rubrioperculatus*, hook size No. 15 selected immature *L. lentjan*, *L. rubrioperculatus* and *Aprion virescens*, while hook size No. 16 selected immature *A. virescens* and *L. rubrioperculatus.* Species similarity was higher for fish caught by hook sizes No. 16 and 15, and No. 8 and 9, while those captured by hook size No. 10 differed from those caught by other hook sizes. The larger hook size No. 8 is recommended for the sustainable exploitation of species in the artisanal handline fishery in Shimoni fishing area. Future work needs to consider the effects of bait type and size and the stock status of the fish under exploitation.

Keywords: Artisanal handline fishery; hook size; species selectivity; Shimoni fishing area

Introduction
Globally, small-scale coastal and marine fisheries support the livelihoods of thousands of fisher folks providing food, fish protein and income to coastal communities. In Kenya, landings from the small-scale coastal marine fisheries average »9,134 Mt/year, valued at »KES 1.3 billion (Government of Kenya, 2013). The fishery directly supports about 13,000 fishers employing various fishing gear and vessel types (Government of Kenya, 2016). The number of handlines has increased over the years from about 4,100 in 2008 to over 6,000 lines in 2014, indicating a substantial increase in fishing effort in the fishery (Government of Kenya, 2012; 2014). However, there was a decrease in the number of handlines to 4, 364 in 2016 (Government of Kenya, 2016). At Shimoni, handlines contribute the highest effort by fishers (1,265 fisher days) compared to other gears. However, handline fishery catches are relatively low at 622kg per month, compared to other gears (Okemwa *et al.*, 2015).

The handline fishery also plays an important role in the broader western Indian Ocean region, with Mozambique recording the highest number of about 12,683 handlines, comprising 23% of the total of 42,300 fishing gears in 2016. In Madagascar, 2,500 handlines were recorded and 356 in Mauritius, while the use of handlines was not recorded in Comoros during the same year (Jacquet and Zeller, 2007; WIOFish, 2017).

Overfishing and capture of juveniles of both target and non-target fish species is likely to threaten the sustainability of marine fisheries (Malleret-King *et al.*, 2003; Mangi and Roberts, 2007). Furthermore, gear and species selectivity may also act as a key driver of fish population structure, species composition, trophic structure and the natural structure of the stock. Hook size selectivity, a measure of how hooks select fish of different fish sizes, is important in setting up size limits for particular fisheries, and helps guide fisheries management in designing policies and sustainable exploitation

http://dx.doi.org/10.4314/wiojms.v18i1.4

strategies for marine fish populations. Setting up size limits is important in conserving the older and bigger fish individuals whose fecundity levels are usually higher and their spawning periods are often extended compared to smaller individuals (Love *et al.*, 1990; Berkeley *et al.*, 2004; Arlinghaus *et al.*, 2010).

Handlines present some of the most selective fishing gears used by small-scale fishers and their use of handlines has been on the increase, especially in Kwale and Kilifi counties on the Kenyan coast, except in 2016 when there was a slight decrease in the use of handlines (Government of Kenya, 2014, 2016). Despite the increased use, many aspects of the handline fishery have not been studied comprehensively. In particular, data and information on the selectivity of handline hooks used in the small-scale coastal marine fisheries is lacking. This study provides baseline information for the sustainable management of the small-scale handline fishery along the Kenyan coast.

Numerous studies have been conducted on the small-scale fisheries of Kenya, from biological, ecological and socio-economic analyses (Stergiou and Erzini, 2002; Fulanda, 2003; Mangi, 2006; McClanahan *et al.*, 2008; Fulanda *et al.*, 2009, 2011; Munga *et al.*, 2011, 2012, 2013). However, studies on the different aspects of the handline fishery, including hook and line, longlines and related fishing gears are clearly lacking. Some studies have assessed hook selectivity in longline fisheries (Løkkeborg and Bjordal, 1992; Erzini *et al.*, 1996; Ekanayake, 1999; Peixer and Petrere, 2007) with little attention given to the handline fishery locally, regionally and globally. Therefore, there is need to assess the selectivity of different hook sizes in the coastal and marine artisanal handline fishery so as to establish suitable hook size limits for sustainable exploitation.

Hook size selectivity is useful in formulating species-specific management recommendations, hence the characterization of the selectivity of handline hooks for the small-scale fisheries of Kenya cannot be understated. The aim of this study was to assess hook size selectivity for the handline fishery in the Shimoni fishing area on the south coast of Kenya through sampling artisanal handline catches, determining the size frequency distribution of the fish species captured, and evaluation of the impact of handline hooks on the fish stocks.

Materials and methods

Study Area

This study was conducted in Shimoni fishing area straddling 04°38’49” S and 39°22’49” E (Fig. 1). The study area has distinct seasonality influenced by the movement of the Inter-tropical Convergence Zone (ITCZ) that creates two distinct seasons; the northeast monsoon (NEM), locally known as ‘kas kazi’ and the southeast monsoon (SEM), or ‘kusi’. The SEM season prevails from April to October and is characterized by wet, windy and cooler weather accompanied by rough seas. The NEM season prevails from November to March and is characterized by warmer weather with calm seas and smaller wave heights (McClanahan, 1988).

The mean annual rainfall in Shimoni, south coast Kenya ranges from 1000–1600 mm and occurs during two distinct periods; the long rains last from March to May while the short rains are experienced during the months of October to December (Mutai and Ward, 2000; Camberlin and Phillipon, 2002). The sea surface temperature ranges between 24°C in August and 30°C in February, and the air temperature ranges from 24°C during July-August to 33°C in February-March, with a mean monthly evaporation rate of 1300-2200 mm (McClanahan, 1988; Swallow *et al.*, 1991; UNEP, 1998). Four oceanic currents influence the eastern Africa coastal waters; the East Africa Coastal Current (EACC), the Somali Current (SC), the Southern Equatorial Current (SEC) and the Equatorial Counter Current (ECC). The former two currents cause high productivity of the water (UNEP, 1998).

The artisanal fishery in the study area is dominated by the handline fishery compared to other areas of the Kenyan coast (Government of Kenya, 2012). The study was conducted at four selected sites within the Shimoni fishing area dominated by handline fishery namely; Mpunguti, Waga, Nyuli and Mundini fishing areas (Fig. 1).

Field Sampling and Data Collection

Sampling was carried out from January to June, 2016, covering the late NEM (January to March) and early SEM (May to June) seasons using experimental fishing. Sampling was conducted for two days each month at each of the four selected sites using a 6 m fibre glass reinforced plastic (GRP) boat powered by a 40 hp outboard engine. Five hooks of different sizes (Youvella® brand round bend type; No. 16, 15, 10, 9 and 8 with the widths (Mean ± SD, mm) of 6.3 ± 0.1, 7.2 ± 0.1, 11.4 ± 0.1, 12.9 ± 0.1 and 15.0 ± 0.1mm, respectively, were used (Fig. 2). The mean widths of the hooks, which correspond to the gape size of fish, were determined by measuring and averaging the width of 20 hooks of each hook size. The numbering of hooks follows the order that the size decreases as the number increases (Bishop, 2019).

The hooks were attached to monofilament nylon lines of 0.30, 0.40, 0.50, 0.60 and 0.70mm thickness, respectively. The thickness of nylon lines was determined by the size of the hooks, thus large sized hooks were used with thicker lines, and vice *versa*. The experimental fishing was preferred to sampling the catches landed by the artisanal fishers in order to ensure full control over the use of the hooks and minimize bias in the method of fishing employed to collect the samples.

All the hooks were baited with equal-sized pieces of frozen squid. Depending on the water depth and current speeds, lead sinkers of varied weights were attached at the fore-tip of the fishing lines to ensure that the hooks sank but remained above the sea bed to allow the bait to attract the fish. Fishing was conducted in the morning between 08h00 and 12h00 and during the night between 23h00 and 05h00, although the latter was only conducted when weather and currents were too rough to allow for daytime fishing. The order in which the hooks were fished was alternated randomly on every fishing trip with each fisher using one specific size of hook on each fishing trip.

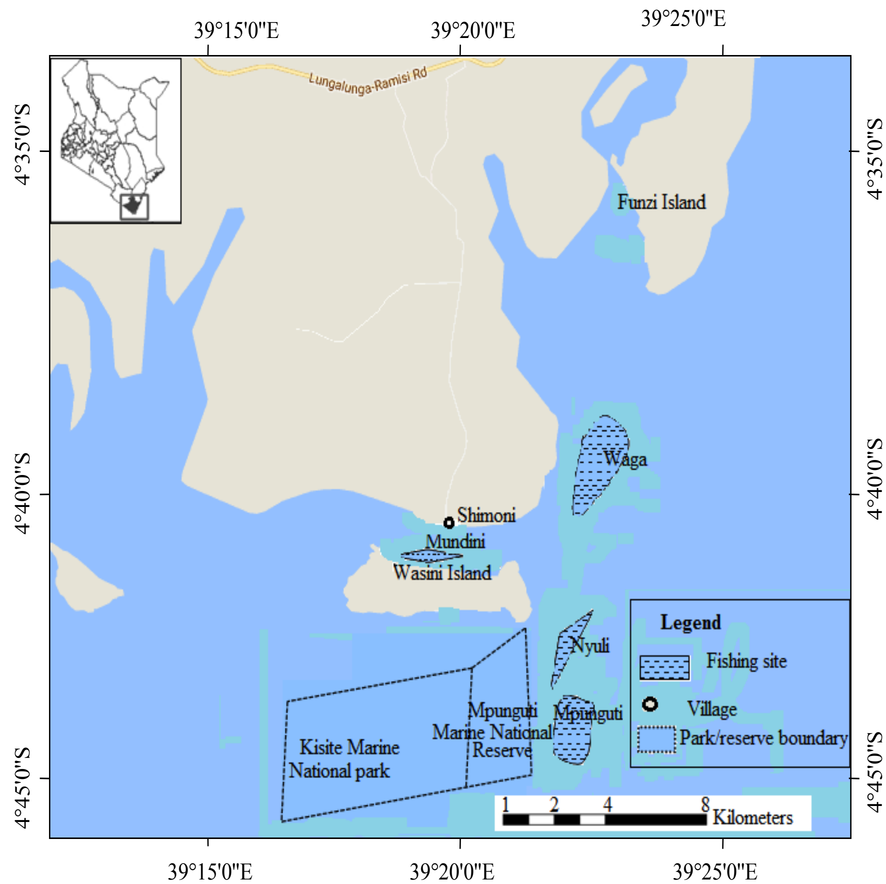

Figure 1. A map of Kenya (inset) showing the south coast and the location of the study sites.

At the fishing grounds, all fish caught were sorted according to hook sizes, placed in cooler boxes and transferred to Shimoni landing site for further sample categorization. All the specimens were sorted to species level at the landing site and identified using fish identification guides (Lieske and Myers, 2001; Anam and Mostarda, 2012). Fish that could not be identified at the landing site were photographed and later identified in the laboratory at Kenya Marine and Fisheries Research Institute (KMFRI) using additional fish identification guides including Fisher and Bianchi (1984) and Smith (2003). The total length (TL) of all the specimens

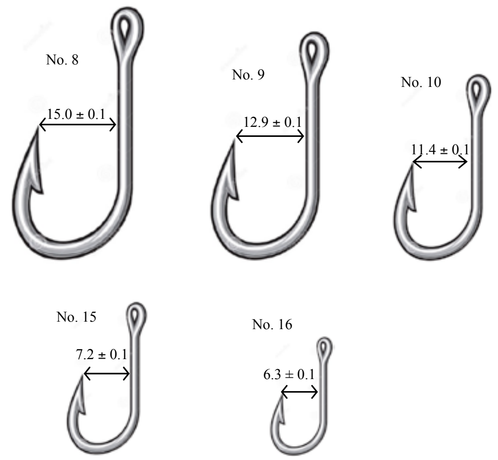

Figure 2. Width (mm) of hooks (No. 8, 9, 10, 15 and 16) used to fish during the experiment.

was measured from the tip of the snout to the tip of the caudal fin, with the tail fin pinched together, to the nearest 0.1cm using a standard fish-length measuring board. Body weight was measured to the nearest 0.01g using a hand-held portable electronic weighing balance (Weiheng, W40kg /10g, Japan).

Data Analysis

Data was entered into an MS Excel spreadsheet and cleaned by confirming that species and family names were correctly written, and the fish measurements were entered in the respective columns. The number of fish caught for all species was determined for the various hook sizes to evaluate the species with representative data for selectivity analysis. The length data was grouped into 2cm size classes and data tallied into a table showing the length classes against the number of observations (specimens), or frequencies in each class for the different hooks used during the study. This was done for each species which had a frequency that could be tallied into the 2cm length classes and gave continuous catch proportions for at least one pair of corresponding hook sizes. Holt's (1963) model as explained by Pauly (1984) was used to determine the catch proportions for the various hook sizes that were plotted against the mid lengths of the length classes to obtain the selectivity curves for the different hook sizes. Holt's (1963) model was used, as the population size in the fishing areas was not known. Pauly (1984) explains Holt's (1963) model using a set of stepwise equations (equations i-vi) as illustrated below. First, the natural logarithms, *Ln*, of the catch ratios of the bigger hook to that of the smaller hook were determined using equation (1):

$$Ln = {}^{C_1}\!/_{C_2} \quad \text{……………………..……Equation (1)}$$

Where: C_1 are the catches from the larger hook and C_2 are catches from the smaller hook for each pair of hook sizes. The natural logarithms of the catch ratios (*Ln*) were regressed against the mid-point of the length class to obtain the intercept and slope, '*a*' and '*b*' respectively.

The selectivity factor (*SF*) was obtained using the '*a*' and '*b*' values

$$SF = \frac{-2a}{b(M_1 + M_2)} \quad \text{………….…….Equation (2)}$$

Where:
SF is the selectivity factor,
'*a*' is the intercept and '*b*' is the slope, both from the regression line,
M_1 is the gape size (mm) of the smaller sized hook, and
M_2 is the gape size (mm) of the larger sized hook for each pair of hooks.

Optimum catching lengths (L_{opt}) for the smaller sized hook (L_{M1}) and larger sized hook (L_{M2}) were calculated using equations (iii) and (iv), respectively. When two estimates of L_{opt} were obtained for the same hook size due to comparison of two length-frequency distributions, their mean value was taken as the L_{opt} corresponding to the particular hook size:

$$L_{M1} = SF \ x \ M_1 \text{……………………..Equation (3)}$$

$$L_{M2} = SF \ x \ M_2 \text{…………….………Equation (4)}$$

Where:
L_{M1} is the optimum catching length for the smaller hook at every length class,
L_{M2} is the optimum catching length for the larger hook at every length class,
M_1 is the gape size (mm) of the smaller hook, and
M_2 is the gape size (mm) of the larger hook for each pair of hooks.

The common standard deviations (S^2) of the two corresponding hooks were calculated using the following equation:

$$S^2 = SF \ x \ \frac{M_2 - M_1}{b} \quad \text{……………Equation (5)}$$

Where,
'*b*' is the slope
S^2 is the common standard deviation of the corresponding pair of hook sizes

SF is the selectivity factor,
M_1 is the gape size (mm) of the smaller hook, and
M_2 is the gape size (mm) of the larger hook for each pair of corresponding hook sizes.
The common standard deviations of the hooks were then employed to determine the catch proportions, *SL*, for the corresponding hook sizes as shown in equation (6):

$$SL_{M1} = exp\ \{-\frac{(L-L_{M1})^2}{2\ x\ S^2}\} \quad \text{.........Equation (6)}$$

Where:
SL_{M1} is the catch proportion at each length class,
L_{M1} is the optimum catching length for the smaller hook at every length class,
L is the midpoint of each length class, and
S^2 is the common standard deviation for the two corresponding hook sizes.

The catch proportions were then plotted against the midpoints of the length class in Microsoft® Excel 2007 to generate selectivity curves for the individual hook sizes separately.

The selectivity ranges of the respective hook sizes were subsequently determined from the width of the selectivity curves, and the optimum length (selectivity) of fish caught by the different hook sizes was estimated from the highest point (mode) of the selectivity curves. The approach of Holt, 1963 model was not applied to all species caught during the study period because it calculates ratios of catches across pairs of hook sizes, and to avoid highly variable ratios, counts that were not sufficient were avoided (Holt, 1963). The length at maturity (L_{mat}) and the maximum length attained when the fish is fully grown (infinite length, L∞) for the dominant species was compared with the optimal selection lengths of the different hook sizes to establish the impact of the hooks on the fish stocks according to Froese and Pauly (2017).

Catch rate by hook size was calculated based on daily catches (kg) for all the hooks of the same size, divided by the number of hooks for each size used to fish on a single day (kg/hook/day), both for each season and the entire period, as calculated below:

$$\text{Catch rate (hook size No. 8)} = \frac{\text{Total catch of all hooks of size No. 8 used in fishing (kg)}}{\text{Number of hooks of size No. 8 used in fishing (TN hooks)}}$$

Statistical Analysis

The difference in mean seasonal catch rate was determined with the student's t-test using STATISTICA© (ver. 7.0.61.0) software (Hay, 1988). Species abundance and distribution across sites, season and hook sizes were assessed using *K*-dominance curves (Warwick *et al.*, 2008). The abundance of each fish species was cumulatively ranked against the log of the species rank using the method adopted from Jennings *et al.* (2001). The values of *K*-dominance against species rank were then plotted into a graph to produce the *K*-dominance curves for each species. Species diversity is reflected in the slope of the curve; a steep and more elevated curve represents a less diverse species assemblage, while small and more gentle gradients indicate high species diversity, and where the *K*-dominance curves cross, they indicate points of similarity in the species dominance (Rice, 2000). This analysis was executed in PRIMER-E (ver. 6.1.5) software (Clarke and Gorley, 2006).

The species abundance data for each hook size was square root transformed to a normal distribution curve, after which Bray-Curtis (1957) similarity analysis was used to evaluate the similarity of species caught by the different hook sizes during the study period. Two dimensional dendrograms were used to sequentially link the relative abundances of all fish species according to their similarity or dissimilarity using the method adopted from Clarke and Warwick, (2001) in PRIMER-E ver. (6.1.5) software. The vertical axis of the dendrogram indicates the percentage level of similarity for the different hook sizes in a cluster (Clarke and Gorley, 2006). Before analysis, the data was subjected to a normality test (of the total length distribution data) using the Shapiro-Wilk's W-test (Shapiro *et al.*, 1968). Thereafter, Analysis of Covariance (ANCOVA) was employed to determine the effect of hook size, season and sampling sites on the size of fish caught during the study period, using the method described by Yang and Juskiw, (2011). All tests were considered significant at the 95% confidence level ($\alpha = 0.05$).

Results

Catch Composition

A total of 966 specimens belonging to 65 species of 23 families were sampled during the study period. The numbers of specimens caught from each of the fishing grounds were: Nyuli (347), Mpunguti (337), Waga (166) and Mundini (116). The smaller hooks (No. 16) caught the highest number of fish (290 specimens) during

Table 1. Number of fish caught at each study site by the different hook sizes during the study period.

Fishing ground /hook size	No. 8	No. 9	No. 10	No. 15	No. 16	Total
Nyuli	19	53	115	53	107	347
Mpunguti	44	35	135	87	36	337
Waga	_	_	1	93	72	166
Mundini	_	_	_	41	75	116
Grand Total	63	88	251	274	290	966

the sampling period while hook size No. 8 caught the lowest number of fish (63 specimens) compared to hook sizes No. 15, 10 and 9, with 274, 251 and 88 specimens, respectively (Table 1). These results show that the abundance of fish capture decreased with increase in hook size. Hook sizes No. 8 and 9 did not catch any fish at Mundini and Waga fishing grounds while hook size No. 10 did not capture any fish at Mundini fishing ground (Table 1). During the experimental fishing eight hooks (four (4) of size No. 16, two (2) of size No. 8 and two (2) hooks of size No. 15) were lost and were not considered in the analyses.

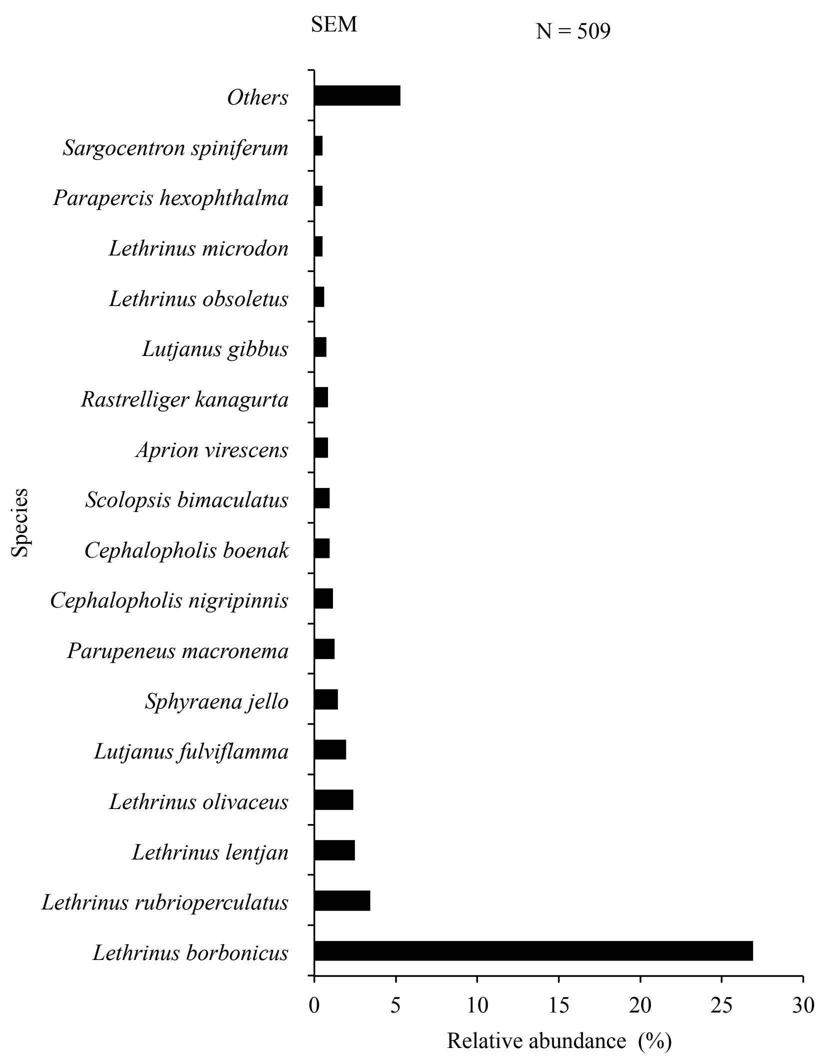

Figure 3. Relative abundance (%) of the fish species caught during the southeast monsoon (SEM) season.

Seasonal Catch Variation

A total of 509 fish weighing 204.92 kg were caught during the SEM season with the Snubnose emperor, *Lethrinus borbonicus* Valenciennes, 1830 being the most abundant, representing 51.1% of the total catch in this study (Fig. 3). During the NEM season, a total of 457 fish weighing 165.87 kg were landed, dominated by Pink-ear emperor, *Lethrinus lentjan* Lacepède, 1802, representing 13.8% of the total catch (Fig. 4). Fish species with smaller proportions were grouped together as 'others' with this category being more abundant during the calmer NEM season than the rougher SEM season.

Hook size No. 8 had the highest mean catch rate during both the NEM and SEM seasons, at 1.29 ± 0.74 kg/hook/day during NEM, and 0.67 ± 0.28 kg/hook/day during SEM season. Hooks sizes No. 8, 9 and 10 gave the highest mean catch rates during the NEM season compared to the catches during the SEM season, while hook size No. 15 recorded similar mean catch rate for both seasons. On the contrary, the smallest hook size No. 16 recorded lower mean catch rate during the calmer NEM season compared to the rougher SEM season. However, the medium hook size No. 10 recorded the highest total catch during both the NEM and SEM seasons. Student's t–tests indicated that the mean catch rates for hook sizes No. 8 and 9 during the NEM and SEM differed significantly (t = 1.36, P = 0.25 for hook size 8, and t = 1.08, p = 0.31 for hook size 9, respectively). However, the catch rates for hook sizes No. 10, 15 and 16 were not significantly different between seasons (Table 2).

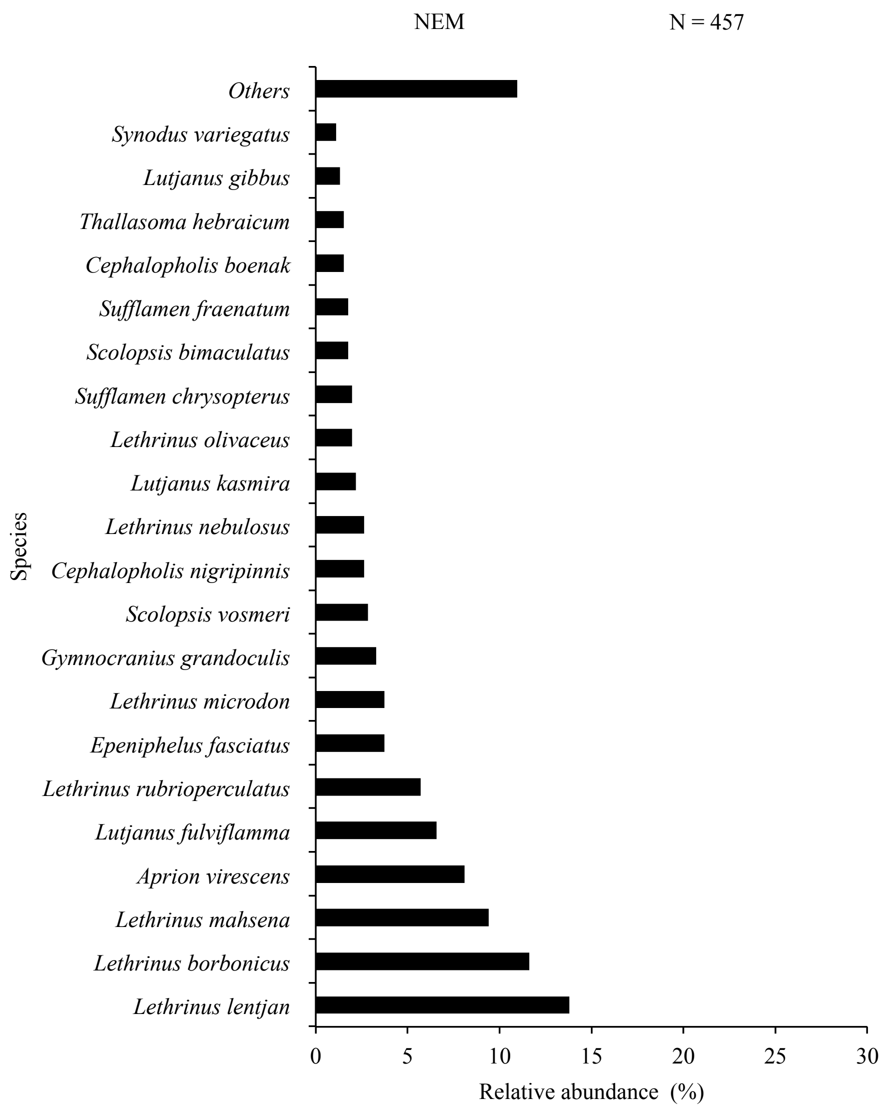

Figure 4. Relative abundance (%) of the fish species caught during the northeast monsoon (NEM) season.

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Table 2. Seasonal mean catch rate (kg/hook/day) for the hook sizes used during the study period.

	NEM		SEM	
Hook size	Total weight (kg)	Mean catch rate ± SD	Total weight (kg)	Mean catch rate ± SD
No. 8	19.6	1.29 ± 0.74	12.4	0.67 ± 0.28
No. 9	14.3	1.12 ± 2.88	6.8	0.15 ± 0.06
No. 10	36.4	0.31 ±0.16	25.2	0.26 ± 0.10
No. 15	22.8	0.13 ± 0.04	17.7	0.13 ± 0.10
No. 16	12.8	0.12 ± 0.05	21.6	0.13 ± 0.08

Species Dominance

The *K*-dominance analysis showed that the curve for the NEM season was lower than that for the SEM season suggesting that fish species dominance was lower during the NEM season; an indication of higher species diversity during this season. The curve for the SEM season showed that species dominance was higher, and hence a lower diversity of fish species during the SEM season (Fig. 5). A comparison of the *K*-dominance curves for the different hook sizes showed lower species dominance for hook sizes No. 15, 16 and 10 while for the other two hook sizes, No. 8 and 9, the curves showed higher dominance (Fig. 6). These results show that the diversity of fish species caught by hook sizes No. 15, 16 and 10 was higher than the diversity of fish species caught by hook sizes No. 8 and 9 during the study period.

A comparison of the *K*-dominance curves for the different study sites showed lower species dominance for Mpunguti and Nyuli fishing grounds, while for Mundini and Waga the curves showed higher species dominance (Fig. 7). These results show that the diversity of fish species caught at Mpunguti and Nyuli was higher than the diversity of fish species caught at Mundini and Waga during the study period.

Effects of hook size, season and fishing ground interaction on the size of fish caught

ANCOVA showed that the size of hooks alone did not have a significant effect on the length of fish caught during the study period (p = 0.12), but fishing ground had a significant effect on the size of fish captured ($p < 0.05$). The interaction of season and sampling site had a significant effect on the length of fish caught during the study period ($p < 0.05$). The interaction of season and hook size; fishing ground *versus* hook size, had no effect on the length of fish captured (p = 0.884 and p = 0.057), respectively. Similarly, the interaction of season, sampling site and hook size had no effect on the length of fish captured during the study period (p = 0.195; Table 3).

Selectivity

Selectivity of all the hook sizes used during the study period was determined for *L. borbonicus*, four

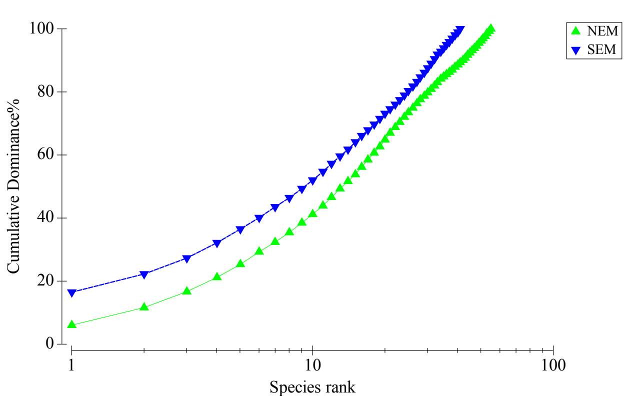

Figure 5. *K*-dominance curves for the fish species caught during NEM and SEM seasons.

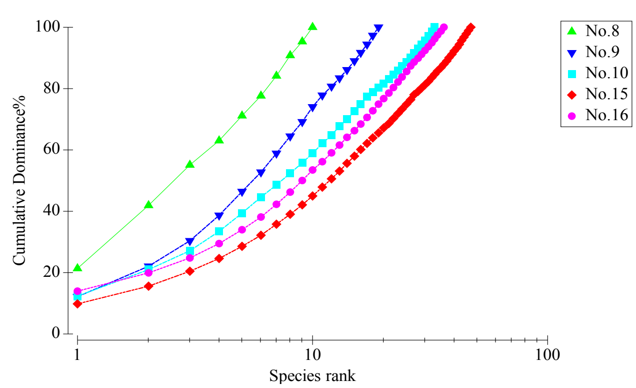

Figure 6. *K*-dominance curves for the fish species caught by the different hook sizes during the study period.

Table 3. P–values for the Analysis of Covariance (ANCOVA) on the effects of season, fishing site and hook size on the length of fish captured during the study period.

Effect	SS	MS	F	P
Season	---	---	---	---
Fishing site	563	563	10.06	0.002
Hook size No.	135.4	135.4	2.42	0.12
Season*Fishing site	262.3	262.3	4.69	0.031
Season*Hook size No.	1.2	1.2	0.02	0.884
Fishing site*Hook size No.	687.9	114.7	2.05	0.057
Season*Fishing site*Hook size No.	484.1	80.7	1.44	0.195

hook sizes for *L. lentjan* and *L. rubrioperculatus*, and two hook sizes for *A. virescens* and *L. fulviflamma*. The length at which *L. borbonicus* matures is 21.3cm and it grows to a maximum length of 40.0cm (Froese and Pauly, 2017) as indicated in Appendix 1. All the hook sizes used for the study period had optimal selection lengths above the length at which *L. borbonicus* matures, showing that all the hook sizes selected mature *L. borbonicus* individuals. Hook sizes No. 9 and 10 had optimal selection lengths above the maximum length for *L. borbonicus*, while hook sizes No. 8, 15 and 16 had optimal selection lengths below maximum length of this species. This implies that hook sizes No. 9 and 10 caught *L. borbonicus* individuals which had attained maximum growth size, while hook sizes No. 8, 15 and 16 caught *L. borbonicus* individuals which had not attained maximum growth size. Selection curves for all hook sizes used during the study period had wide selection ranges for *L. borbonicus*, except for hook size No. 8 which showed a narrow selection range (Fig. 8).

The length at which *L. lentjan* matures is 24.7 cm and the fish grows to a maximum length of 52.0cm (Froese and Pauly, 2017) as shown in Appendix 1. Hook sizes No. 15 and 8 had optimal selection lengths less than the length at which *L. lentjan* matures indicating that the hooks selected immature *L. lentjan* individuals. On the other hand, the optimal selection lengths of hook sizes No. 10 and 9 were above the length at which *L. lentjan* matures (Fig. 9). This indicates that hook sizes No. 10 and 9 selected mature *L. lentjan* during the study period. However, all the hooks caught *L. lentjan* individuals that had not attained maximum growth size. The length at first maturity for *L. rubrioperculatus* is 20.0 – 26.0 cm and it grows to a maximum length of 50.0cm (Froese and Pauly, 2017; Appendix 1). The optimal selection length of hook sizes No. 16 and 15 was less than the length at which *L. rubrioperculatus* matures while the optimal selection length of hook sizes No. 10 and 9 was above this length. This indicates that hook sizes No. 16 and 15 captured immature *L. rubrioperculatus* individuals and hook sizes No. 10

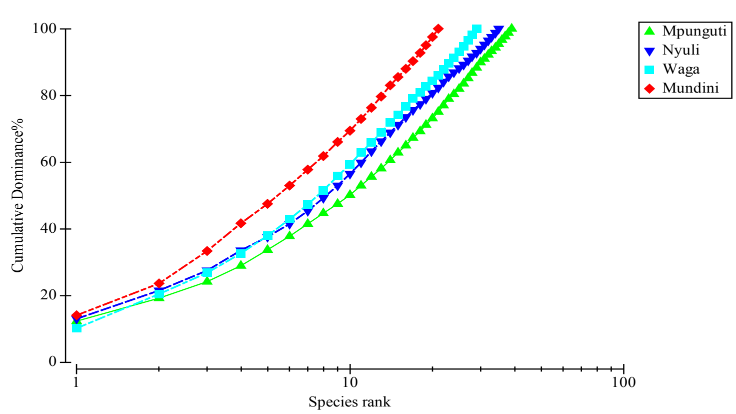

Figure 7. *K*-dominance curves for fish species caught at the study sites during the study period.

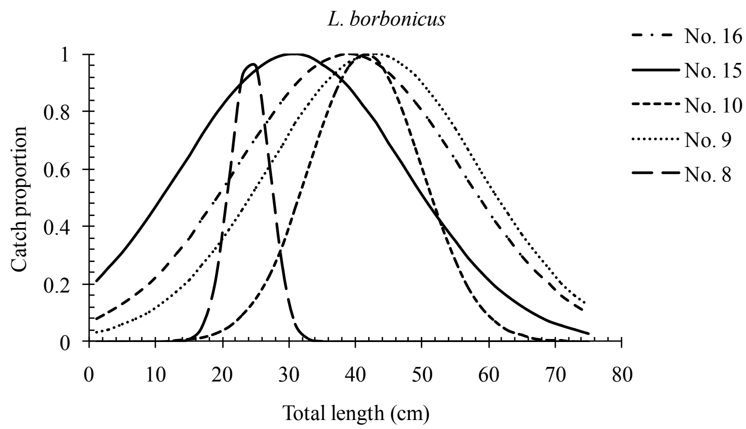

Figure 8. Selectivity curves for the various hook sizes used to capture *Lethrinus borbonicus* specimens during the study period.

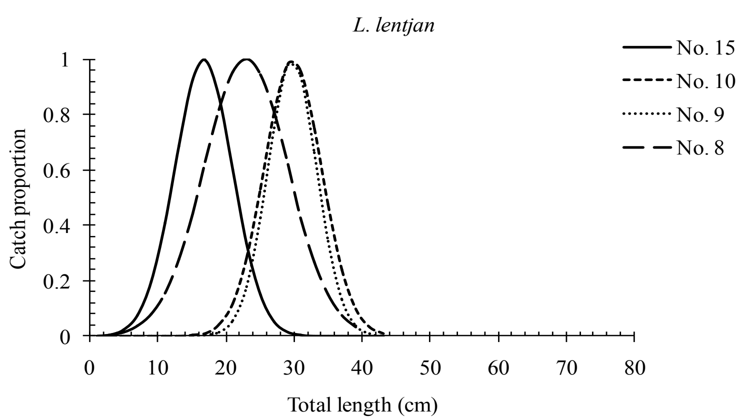

Figure 9. Selectivity curves for the various hook sizes used to capture *Lethrinus lentjan* specimens during the study period.

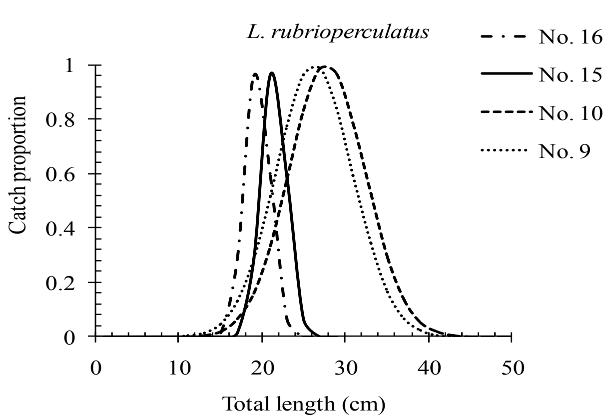

Figure 10. Selectivity curves for the various hook sizes used to capture *Lethrinus rubrioperculatus* specimens during the study period.

Table 4. Number of specimens per species, mean length (± SD, cm) and optimal selection length (cm) of the hooks used for the study.

Species	N	Mean Length (cm)	Optimal selection length (cm)				
			No.16	No.15	No.10	No.9	No.8
L. fulviflamma	49	19.0 ± 3.3	19	21	_	_	_
A. virescens	45	21.7 ± 15.9	7	9	_	_	_
L. rubrioperculatus	59	20.4 ± 3.6	19	21	27	27	_
L. lentjan	87	25.5 ± 5.3	_	17	29	29	23
L. borbonicus	313	19.9 ± 4.2	39	31	41	43	25

and 9 captured mature *L. rubrioperculatus* individuals during the study period. The optimal selection length of hook sizes No. 16, 15, 10 and 9 were less than the maximum length attained by *L. rubrioperculatus* (Fig. 10). This indicates that the hooks captured *L. rubrioperculatus* individuals before they had attained their maximum growth size.

Lutjanus fulviflamma matures at a length of 17.1cm and grows to a maximum length of 35.0cm (Froese and Pauly, 2017; Appendix 1). The optimal selection lengths for hook sizes No. 15 and 16 (21.0cm and 19.0cm, respectively) were above the length at which *L. fulviflamma* matures indicating that hook sizes No. 15 and 16 selected mature *L. fulviflamma*. However, the

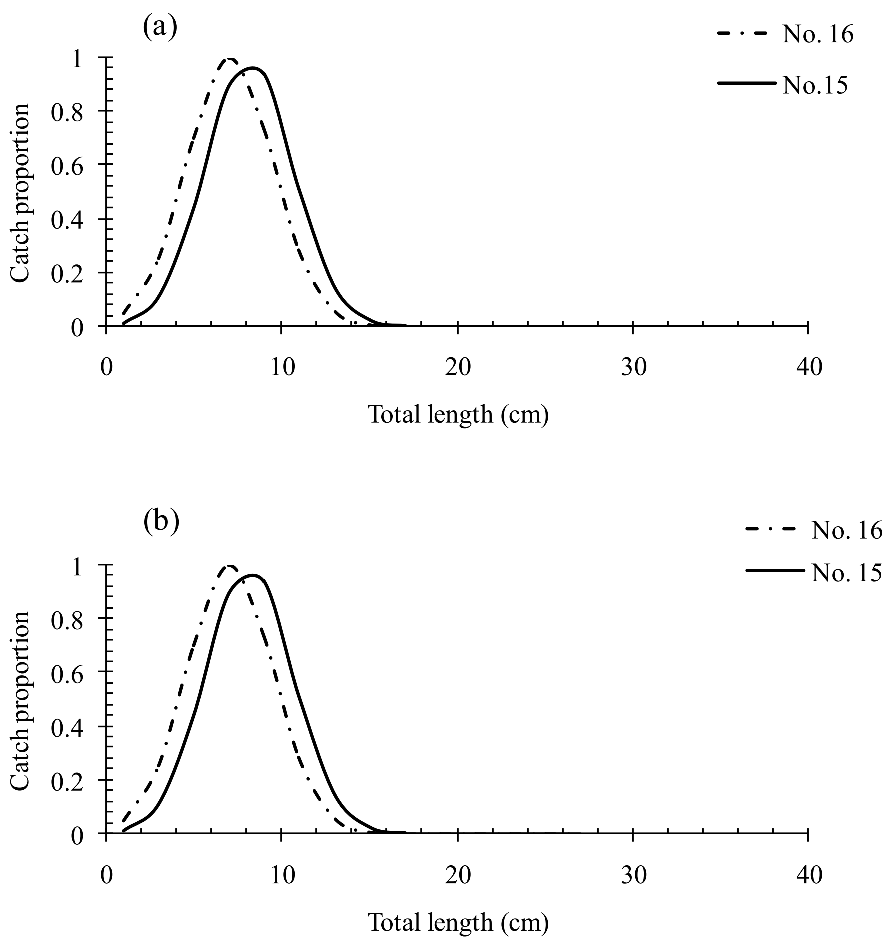

Figure 11. Selectivity curves for hook sizes No. 16 and 15 that captured *Lutjanus fulviflamma* (a) and *Aprion virescens* (b) specimens during the study period.

optimal selection lengths were less than the maximum length attained by *L. fulviflamma* indicating that hook sizes No. 15 and 16 captured *L. fulviflamma* individuals which had not attained maximum growth size.

Aprion virescens matures at a length of 44.7 cm and grows to a maximum length of 112.0cm (Froese and Pauly, 2017; Appendix 1). The optimal selection lengths for hook sizes No. 16 and 15 (7.0cm and 9.0cm, respectively) were lower than the length at which *A. virescens* matures and this indicated that both hook sizes No. 16 and 15 selected immature *A. virescens* during the study period. Also, hook sizes No. 16 and 15 captured *A. virescens* which had not attained maximum growth size (Fig. 11 a & b).

Hook size No. 16 had the same optimal selection length (19.0cm) for *L. fulviflamma* and *L. rubrioperculatus*, while hook sizes No. 10 and 9 had the same optimal selection length for this species (27.0cm). Similarly, hook sizes No.10 and 9 had the same optimal selection length (29.0cm) for *L. lentjan* during the study period (Table 4).
Similarity of species composition for the fish caught by the different hook types

Hierarchical cluster analysis was carried out to investigate the similarity of fish species composition for the different hook sizes used during the study period (Fig. 12). There was a high level of similarity in the species caught by hook sizes No. 16 and 15 (64.9%). Also, the fish species caught by hook size No. 8 were similar to those captured by hook size No. 9 (46.3%). This shows that the fish species caught by hook size No. 16 were comparable to those caught by hook size No. 15, while the species caught by hook size No. 8 were comparable to those caught by hook size No. 9. Hook size No. 10 can singled out, with fish species not similar to those caught by the other hook sizes used during the study period (Fig. 12).

Discussion

Hook size has considerable effects on the size and composition of fish captured. This study assessed fish size selectivity of different hook sizes to ascertain whether the use of large sized hooks could reduce the capture of undersized individuals in the artisanal handline fishery of Shimoni on the south coast of Kenya. This was achieved by assessing the species composition of fish captured by five different hook sizes (Nos. 16, 15, 10, 9 and 8) and estimating the optimal selection lengths of the hooks for the most abundant species captured. The results indicated that there was a higher diversity of fish species caught during the calmer NEM season compared to the rougher SEM season. This could be due to reduced fishing effort as a result of rough sea conditions during the SEM, or migration of fish and reduced density due to a deeper thermocline and cooler waters in the SEM (McClanahan, 1988).

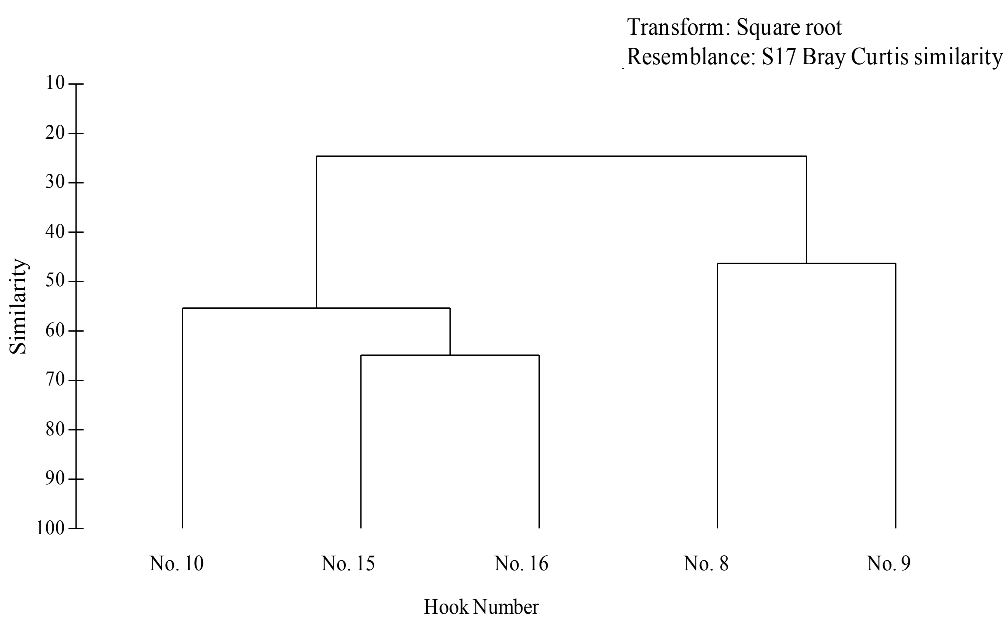

Figure 12. Cluster analysis dendrogram showing the similarity in species composition for various hook sizes.

Results from this study indicate that small sized hooks captured greater numbers of fish compared to large sized hooks which captured less and larger fish. These results are in agreement with the findings of Bjorndal and Løkkeborg (1996), where smaller hooks produced more fish than larger hooks. Similarly, the smaller hook size No. 12 captured small snappers while the larger hook size No. 8 captured large snappers (Ralston, 1990). In this study the larger hook size No. 8 was more effective in capturing and holding larger fish which gave higher catch rate, and showed lower species diversity compared to the smaller hook size Nos. 15 and 16. These results are in agreement with those of Patterson *et al.*, (2012) in which the diversity of fish caught decreased with an increase in hook size.

The decline of the number of smaller fish with increasing hook size and the abundance of fish could be due to gape limitations (Bacheler and Buckel, 2004) and small hooks being swallowed easily and becoming hooked deeply in the body, reducing the chances of fish escape (Alós *et al.*, 2008). Also, the decrease in the number of fish with an increase in hook size from this study concur with the findings of Mongeon *et al.* (2013) where the smaller hook size No. 10 caught more spotted rose snappers, *Lutjanus guttatus* than the large hook sizes No. 6 and 8. The results clearly indicate that there was an increase in the length of fish caught with increase in hook size and this could be as a result of large fish avoiding small hooks or the limitations of the mouth sizes of fish. These results concur with those obtained from a study conducted by Otway (1993) where an increase in absolute hook size led to a substantial increase in the mean size of snappers captured.

Results of this study showed that the sizes of fish caught at Mpunguti fishing ground did not differ from the sizes of fish caught at Nyuli. Similarly, the sizes of fish caught at Waga did not differ from the sizes of fish caught at Mundini fishing ground. However, there was higher species diversity at Mpunguti and lower species diversity at Mundini. This could be attributed to differences in fish size composition and species composition at the fishing grounds. The results indicated that the size of hooks alone did not have any effect on the size of fish captured, but different fishing grounds resulted in variations in the size of fish captured. This could be attributed to differences in the size composition of fish in the fishing grounds. A combination of both season and fishing grounds led to variations in the total length of fish caught, and could be an indication that the sizes of fish were influenced by season. However, when both season and hook size or fishing ground and hook size are changed, the length of fish caught did not change. Also, a simultaneous change of season, fishing ground and hook size did not change the total length of fish caught during this study.

The decrease in selection length with increase in hook size recorded for *L. borbonicus* agrees with the findings of Amarasinghe *et al.* (2014) in which the selection range of the giant trevally, *Caranx ignobilis*, and the naked breast trevallay, *Carangoides gynostethuse*, decreased with increase in hook size. The lower selection ranges for hook sizes No. 15 and 16 shown in *L. fulviflamma* and *A. virescens* selection curves could be as a result of large fish avoiding these hooks and the failure of these hooks in retaining large fish. The findings of this study show important differences in terms of the number of fish caught by different hook sizes and this could be due to the preference of the fish to the different hook sizes, the size of mouth gape or the size composition of the fish poulations. The smaller hook sizes No. 16, 15 and 10 caught large numbers of fish resulting in high species diversity compared to the larger hook sizes No. 8 and 9 which caught less numbers of fish, resulting in low species diversity.

In this study selectivity was determined for only five species (*L. borbonicus*, *L. lentjan*, *L. rubrioperculatus*, *L. fulviflamma* and *A. virescens*) and for those hooks which produced representative data. The lack of selectivity analysis for the other species caught by the handlines could be due to limited size ranges in the fishing areas (Erzini *et al.*, 1996), or an overlap in the length frequency distribution of fish and low variation in the sizes of fish captured, making curve adjustment difficult (Peixer and Petrere, 2007). The selection characteristics of *L. borbonicus*, *L. lentjan*, *L. rubrioperculatus*, *L. fulviflamma* and *A. virescens* indicated unimodal curves for the different hook sizes used during the study. This conforms to the principle of geometric similarity which states that all fish of the same species which are geometrically similar are caught by geometrically similar gears producing similar selection curves (Baranov, 1948; Hamley, 1975). These findings are similar to those recorded for masu salmon, *Oncorhynchus masou* (Shimizu *et al.*, 2000), yellowfin tuna, *Thunnus albacores* (Cortes-Zeragoza *et al.*, 1989), and for the giant trevally, *Caranx ignobilis*, together with those of the naked breast trevally, *Carangoides gynostethus* caught in the hook-and-line fishery off Nagombo, Sri Lanka (Amarasinghe *et al.*, 2014) which reported unimodal selection curves for the respective species. However, Ralston (1982) and Peixer and Petrere (2007) found that hook selectivity can conform to a sigmoid selection curve which represents yield per recruit (Silvestre and Pauly, 1991).

The selectivity of all the hooks used in this study was above the length at which *L. borbonicus* matures (Table 6) indicating that the hooks did not capture immature individuals. However, the use of hook sizes No. 16, 15, 10 and 9 should be controlled, since they have wider selection ranges, to conserve the older and bigger fish that have high fecundities and longer spawning periods than smaller fish (Love *et al.*, 1990; Berkeley *et al.*, 2004). Hook sizes No. 16 and 15 captured mature *L. fulviflamma* and immature *A. virescens* specimens. These results are controversial when it comes to decision making on whether to avoid these sizes of hooks or not, since the fishery is multispecies. Also, hook sizes No. 15 and 8 captured mature *L. lentjan*, while hook sizes No.10 and 9 captured immature *L. lentjan*. The selectivity of hook sizes No. 15, 10 and 9 (Table 6) revealed that these hooks captured mature *L. rubrioperculatus* fish while hook size No. 16 captured immature *L. rubioperculatus* during the study period.

Generally, these results indicate an overlap in the selectivity of the hook sizes No. 16, 15, 10, 9 and 8 for *L. borbonicus*, *L. lentjan*, *L. rubrioperculatus*, *L. fulviflamma* and *A. virescens*. For certain species the hooks selected mature fish and for other species the specific hooks selected immature fish, making it difficult for decision making in the multispecies fishery. However, the larger hook size No. 8 proved to be the suitable hook for the handline fishery given that these hooks captured mature fish, gave narrow selectivity curves and yielded higher catch rates during the study period.

Conclusion and recommendations

In conclusion, results from the present study indicate that varying hook sizes in the Shimoni artisanal handline fishery had significant effects: smaller hooks caught more fish with higher species diversity compared to the larger hooks that caught less fish with lower species diversity. However, the larger hooks had higher catch rates compared to the smaller hooks. From the results, it can be generally concluded that the selectivity of the different hooks used in this study vary with the fish species. However, the larger hook size No. 8 could be suitable for the Shimoni artisanal handline fishery as it resulted in higher catch rate and a selection curve with narrow selection ranges targeting fewer cohorts, and gave higher yields. This will result in reduced capture of immature individuals and conserve the more productive older fish in the population (Arlinghaus *et al.*, 2010). However, if the current level of fishing is sustainable, other hooks with wider selection ranges could be used so that more length classes are harvested.

The use of large sized hook No. 8 is therefore recommended for the Shimoni artisanal handline fishery, which resulted in a higher catch rate and narrower selection ranges compared to the smaller sized hooks. This analysis was done without consideration of the hooks which got lost due to fish escapes, size of fish mouth, bait type and duration of soaking for specific hook sizes. Therefore, it is recommended that a study be conducted to address these aspects, and to assess the stock status of fish populations in the fishing area to allow for the application of other methods of determining selectivity such as "iterative estimates" (Regier and Robson, 1966)), and McCombie and Fry's (1960) methods to give absolute selectivity for the fishery, and for comparisons. Given the diversity of fish species caught by the handline fishery, a multispecies assessment approach would be required, or hook selectivity should be evaluated through single species assessment techniques.

Acknowledgements

This study was supported by the Western Indian Ocean Marine Science Association (WIOMSA) and National Commission for Science, Technology and Innovation (NACOSTI) grant [Ref NO. NACOSTI/RCD/ST& I/7TH CALL/MSC/204]. We acknowledge the many people who helped to make this study possible. First and foremost we would like to thank the Director of the Kenya Marine and Fisheries Research Institute and staff who offered support and space to do the work; particularly Mr. Elija Mokaya, the librarian, for providing relevant reference materials, Mr. Ocharo Daniel, the field technician at KMFRI Shimoni for his support during field work, Mr. Kaka Shaame and Mr. Mtwana A. Makame, fishermen at Shimoni landing site, for their cooperation all through the sampling period. We appreciate the Department of Biological Sciences, Pwani University for their academic and moral support during this study.

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Appendix 1. Family, species, number of fish (N), size range, length at 1st maturity, L_{mat} and infinite length, L¥ (Froese and Pauly, 2017) of the fish species caught during the study period.

Family	Species	N	Size range (cm)	L_{mat} (cm)	L ∞ (cm)
Lethrinidae	*Lethrinus borbonicus*	313	11.0–34.0	21.3	40.0
Lethrinidae	*Lethrinus lentjan*	87	14.9–20.0	24.7	52.0
Lutjanidae	Lutjanus fulviflamma	49	12.2–26.0	17.1	35.0
Lethrinidae	*Lethrinus mahsena*	46	23.6–41.0	19.0	65.0
Lethrinidae	*Lethrinus rubrioperculatus*	59	14.5–29.0	20.0-26.0	50.0
Lutjanidae	*Aprion virescens*	45	11.0–70.5	44.7	112.0
Lethrinidae	*Lethrinus olivaceus*	32	13.7–47.0	34.0	100.0
Lethrinidae	*Lethrinus microdon*	22	19.0–37.0	29.1	80.0
Serranidae	*Epeniphelus fasciatus*	19	12.0–26.0	17.5	40.0
Nemipteridae	*Scolopsis bimaculatus*	17	17.1–24.0	_	31.0
Lethrinidae	*Gymnocranius grandoculis*	16	15.4–38.0	_	80.0
Serranidae	*Cephalopholis nigripinnis*	23	10.5–22.5	_	28.0
Sphyraenidae	*Sphyraena jello*	14	47.2–59.8	_	150.0
Nemipteridae	*Scolopsis vosmeri*	13	11.9–16.6	_	25.0
Lethrinidae	*Lethrinus nebulosus*	13	14.0–19.5	39.4	87.0
Lutjanidae	*Lutjanus gibbus*	13	14.4–44.0	_	50.0
Balistidae	*Sufflamen chrysopterus*	12	14.0–20.6	_	30.0
Lutjanidae	*Lutjanus kasmira*	12	14.5–26.5	_	40.0
Serranidae	*Cephalopholis boenak*	16	10.0–75.0	12.2	30.0
Mullidae	*Parupeneus macronema*	16	14.9–20.0	12.3	40.0
Balistidae	*Sufflamen fraenatum*	11	17.9–32.6	_	38.0
	Others	118			
	Total	966			