Western Indian Ocean
JOURNAL OF
Marine Science

Volume 16 | Issue 1 | Jan – Jun 2017 | ISSN: 0856-860X

Chief Editor José Paula

Western Indian Ocean
JOURNAL OF
Marine Science

Published biannually

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ISSN 0856-860X

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Effects of blood meal as a substitute for fish meal in the culture of juvenile Silver Pompano *Trachinotus blochii* (Lacepède, 1801) in a circulating aquaculture system

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Abstract

A feeding trial was conducted for 12 weeks to evaluate the nutritive value of fermented and un-fermented blood meal as a possible protein source for diets of juvenile silver pompano, *Trachinotus blochii*. The experiments were carried out concurrently in a completely randomized design. A total of 330 fish (10.98 ±0. 5g and 12. 52±0. 01 cm) were stocked in 33 tanks (1000 L) for 8 weeks and fed one of the experimental diets at 10% body weight per day in 3 equal feedings. Eleven isonitrogenous experimental diets (45% crude protein and 12% crude lipid) were prepared by replacing fish meal levels from 5, 15, 25, 35 and 45% with) fermented and unfermented blood meal, and a 100% fish meal based diet was used as a control diet. Fish fed a 35% experimental diet of fermented blood meal and unfermented blood meal exhibited significantly higher growth performance compared to fish fed the control diet of 100% fish meal and 5, 15, 25 and 45% experimental diets replaced with both fermented and unfermented blood meal (weight gain 88.06 – 67.33 g; FCR 1.14 - 1.65; SGR 3.2 - 3.11; and PER 1.94 -1.34) respectively. The overall performance was significant higher in fermented diets (88.06 g at 35%) than unfermented diets (67.33 g). The levels of lipid and ash in the whole body carcass increased as both fermented and un-fermented blood meal substitution in diets increased, whereas protein and moisture decreased in all treatment groups compared with the control. These results showed that approximately 35% of fish meal protein could be replaced by both fermented and unfermented blood meal for juvenile silver pompano without compromising growth performance and feed efficiency, potentially leading to significant cost saving.

Keywords: *Trachinotus blochii*, alternative diets, fermented blood meal, marine fish culture

Introduction

Aquaculture has been the fastest growing food sector over the past two decades worldwide (Mimako *et al.,* 2015). This rapid growth has led to increased demand for key raw materials used in aquaculture feeds such as fish meal and fish oil (Thilsted *et al.,* 2016). Fish meal diets reflect natural diets of fish as they contain a balance of all essential amino acids, minerals, phospholipids and fatty acids (Hardy, 2010; Lund *et al.,* 2012). In 2007 aquaculture industries consumed 87% of global fish oil production. Continued expansion of aquaculture production reflects the global population increase which has resulted in an increased demand for fish protein (FAO, 2010). Global fisheries production has not matched demand for both human consumptions and the aquaculture industry (Hardy, 2010). This situation has led to unaffordable prices of fish meal and fish oil and forced the aquaculture sector to look for alternative ingredients from a wide range of sources, including plant and animal by- products

(Hardy, 2010; Tacon *et al.,* 2011; Lech & Reigh, 2012; Sugumaran & Radhakrishnan, 2015).

Fish meal-based diets are characterized by high digestibility and palatability with adequate amounts of micronutrients, thus identification of ideal replacements is not straightforward (Kaushik & Seiliez, 2010; Lund *et al.,* 2012). For example, the essential omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are basic nutrients required in the diets of farmed larvae and broodstock, are produced by marine plankton and cannot be synthesized by fish. These fatty acids can only be obtained by utilizing fish oil (Baron *et al.,* 2013).

Slaughterhouse wastes, including blood, are potential protein sources that can be utilized to replace fish meal in aquaculture diets (Tacon *et al.,* 2011). Sub-Saharan Africa, including the WIO region, possesses large amounts of livestock such as cattle, sheep and goats, and thousands are slaughtered annually (FAO, 2000). Blood produced in the slaughterhouses is usually deposited in stabilization lagoons or directly discarded into the environment. From an environmental viewpoint it is desirable that the blood from the slaughterhouse is re-used. Drying it to produce blood meal for use as an aquaculture feed ingredient is one option for re-use (FAO, 2000). In aquafeed industries blood meal has received much attention due to a high quality protein content, as a good source of lysine and histidine, a high digestibility of 80-99 %, and the presence of haem-iron together with other forms of iron which may promote oxidation of feed components (Bureau *et al.,* 1999; El-Haroun & Bureau, 2007; Millamena, 2002). Processing affects the blood meal in terms of nutritive quality and digestibility. The spray dried process has been reported to result in a product with excellent protein digestibility (~99%) whereas other drying processes may reduce digestibility to ~80% in rainbow trout (Bureau *et al.,* 1999). On the other hand, fermentation processes have been reported to improve the nutritive quality, digestibility and potability of various feed ingredients in aquaculture diets (Wee, 1999).

Previous research has shown that blood meal can be incorporated up to a level of 6% to 10 % in diets of the grouper, *Epinephelus coioides* (Martins & Guzman, 1994), tambaqui, *Colossoma macropomum* (Martínez-Llorens *et al.,* 2008), and gilthead sea bream, *Sparus aurata* (Ribeiro *et al.,* 2011), and 20% in diets of juvenile trout, *Oncorhynchus mykiss* (Luzier *et al.,* 1995). Moreover, Agbebi *et al.* (2009) reported that fish meal can be replaced completely (100%) by blood meal with no adverse effect on growth, survival and feed conversion in cat fish, *Clarias gariepinus*, juveniles. However, the level of fishmeal replacement was species-specific and varied according to fish size and feeding habits (Barnes *et al.,* 2012; Dedeke *et al.,* 2013). Little is known about the effect of fermented and unfermented blood meal on replacement of fish meal in silver pompano diets. The current study aims to evaluate the effects of different levels of fish meal replacement with fermented and unfermented blood meals on growth performance of juvenile silver pompano. Furthermore, the study examines the influence of different inclusion levels of processed and un-processed blood in the silver pompano carcass composition. Lastly the study evaluates the economic benefit of utilization of blood meal as an alternative source of protein for fish meal replacement in the aquaculture diet of silver pompano.

Methodology

Fish sampling and experimental setup

Juvenile silver pompano were obtained from Nungwi Beach located at the northern tip of Unguja Island, Zanzibar (5.72°S and 39.30°E). Fingerlings were collected using beach seine nets and placed in small net cages within Nungwi Aquarium before being loaded into 100 l tanks equipped with a supplemental oxygen supply system. The collected fingerlings were transported in the early morning and the open tops of the plastic tanks were covered with plastic material to avoid exposure to direct sun light. The tanks were filled with water to 50% of their volume and water exchange was carried out every 30 minutes while the fingerlings were transported by boat to the Institute of Marine Sciences Mariculture Center (IMS-MC) at Pangani, Tanga. Subsequently, ten fingerlings were stocked randomly into each of 1m^3 concrete tanks directly connected to a flow through seawater system and supplemental aeration was provided by a regenerative air blower and air diffusers. The juvenile silver pompano were acclimated to the facilities for two weeks at the experimental site and fed with a commercial fish meal diet to apparent satiation. Fish were cultured under conditions presumed optimal for silver pompano growth (see water quality information below) and fed artificial feed (crude protein = 50% minimum; crude fat = 10% minimum; crude fiber = 3% maximum; crude ash = 6% maximum; average pellet size = 1.mm).

Diet formulation

Fishmeal – control diet (FM)

The fish meal described here was derived from the Indian anchovy (*Stolephorus commersonnii*), a small schooling fish which is found in most tropical areas of the Indian Ocean. In Tanzania anchovy fisheries are artisanal and subsistence and are conducted by women and men in coastal waters. The anchovy were sun dried for 1-2 days, milled and incorporated into feed formulations.

Blood Meal – Fermented (FBML) and Unfermented (BML)

Fresh cow blood was collected from slaughter houses in 10 L buckets. Unwanted materials were removed before sun-drying for 5 days. For blood fermentation, 10% of fermented milk was added before sun drying and thoroughly mixed to facilitate the fermentation process. The mixture was then incubated for 14 days at room temperature, and stirred twice daily. After 14 days the fermented blood meal was sun-dried for 5 days. Both fermented and unfermented blood were ground to powder form using a hammer mill and subjected to proximate analysis. Eleven isonitrogenous (50g $100g^{-1}$), isolipidic (10g $100g^{-1}$), and isoenergetic (19kj) experimental diets were formulated. A diet with fish meal (FM) as the main protein source was used as the control diet (FM). The experimental diets were formulated to produce diets in which 5 (FBML/BML 5), 15 (FBML/BML 15), 25 (FBML/BML 25), 35 (FBML/BML 35) and 45 (FBML/BML 45) % of FM protein was replaced by that of FBML or BML protein. Fish oil, sunflower oil, and vitamins were used at a 1:1 ratio (Table 1). The dietary ingredients were mixed in a food blender with warm water until a soft slightly moist consistency was achieved. This was then cold-press-meat mixer extruded to produce a 1mm pellet. The moist pellets were then sun-dried and stored frozen at -20°C until use.

Feeding Regime

Fish were hand fed 10% of body weight three times per day with ten experimental diets of fermented blood meal, unfermented blood meal, and a control diet. The diets were offered in equal portions at 09:00, 13:00 and 17.00 hours during the twelve weeks of the experiment. Each feeding treatment was randomly assigned to three replicate tanks (n = 3). The ration was adjusted every two weeks according to fish weight with care being taken to avoid feed wastage.

Environmental parameters

Water quality parameters such as dissolved oxygen, salinity, temperature and pH were measured twice daily through the whole period of the experiment at 09:00 and 16:00 with a WTW multi-parameter probe. Water samples for analysis of ammonium ions were collected twice a week in 250 ml plastic bottles and stored frozen at -20°C at IMS-MC for the whole period of rearing of fingerlings. The samples were then transported in an ice box to the IMS in Zanzibar for analysis. The concentration of ammonia in the water samples was determined as in the UNESCO (1993) protocol. Throughout the experiment, photoperiod was kept at a 12 h light: 12 h dark cycle, and tank inflow rates were maintained at 0.5 L/min.

Growth and feed utilization

The initial body weight (IBW), final body weight (FBW), total weight gain (TWG), specific growth rate (SGR - %/day), feed conversion ratio (FCR), protein efficiency ratio (PER), and survival rate (SR%) were

Table 1. Ingredient requirement to formulate blood meal diets for *T. blochii* (100 g).

Parameters	T1-%0	T2-5%	T3-15%	T4-25%	T5-35%	T6-45%
Fish Meal	51	66	55	41	30	20
Blood Meal	0	5	15	25	35	45
Maize	38	19	20	22	25	25
Herrings Oil	5	3	3	5	3	3
Binder	3	3	3	3	3	3
Premix	3	3	3	3	3	3
Total	100	100	100	100	100	100

Premix contains: Vitamin A, D3, E, K, Thiamine B1, Riboflavin B2 Pyridoxine B6, Vitamin B12 Niacin, Pantothenic acid, Folic acid, Biotin, Choline chloride, Antioxidant, Zinc, Iodide, Iron, Cobalt, Selenium

determined according to the methods of De Silva & Anderson (1995). The percentage survival rates were calculated based on Jobling (1996).

Economic Evaluation

The economic evaluation of fermented and unfermented blood meals as alternative protein sources in silver pompano feed was calculated based on the following formulae:

Economic efficiency ratio (ECR) = feed offered (kg) × price index/weight gain (kg)

Percentage Relative Economic efficiency ratio (ECR) = feed offered (kg) × price index/weight gain (kg) x 100

Economic profit index (EPI) = final weight (kg fish-^{1}) × fish sale price (USD kg^{-1}) -
ECR x weight gain (kg)

Pompano sale price was considered as 4.0 USD kg^{-1}.

Price index /weight is the average price per kg

Condition factor (K)

The coefficient of condition was calculated as

Whereby W = Weight of individual fish (g), L = Total length of individual fish, K = condition factor.

Length weight relationship was calculated as $W = a L^{b}$

Length weight data was transformed into common logarithm as log W = log a + b. log L

Where by W = Weight of fish in gram (g)

L = Total length of fish in centimeters (cm)
a = proportionality constant
b = the value obtained from the length - weight equation/coefficient of regression.

In this analysis only three treatments of (FBML 35, BML 35 and FM control) were selected based on growth performance observed during the 12 weeks feeding trial.

Proximate analysis of fish and experiment diets

The proximate compositions of pompano fish before and after the experiment together with feed ingredients were analyzed at the Department of Animal Science and Production of Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. Crude protein, crude lipid, moisture, and ash contents were analyzed for composition. Analyses were performed according to standard methods (AOAC, 1995). Moisture content was determined by drying samples in an oven at 105°C to constant weight. Crude lipid was determined using a Soxhlet extractor with petroleum ether (40-60°C boiling range). Crude protein was determined by the Kjeldahl method using digestion block and steam distillation, and ash was determined by incineration of the feed sample in a muffle furnace at 550°C to constant weight.

Statistical analysis

A completely randomised design (CRD) was used in assigning dietary treatments to culture units. The main statistical hypothesis tested was that there is no significant difference between treatment means (percentage levels of fermented and unfermented blood meals inclusion, and control diets). Two-way analysis of variance (ANOVA) was used to determine differences between treatment means which were deemed significant at $P<0.05$. Post-hoc analysis was carried out where significant differences existed between treatment means using Tukey's Honest Significant Difference Test. Analyses were performed using SPSS software version 21 (SPSS Inc). Before analysis, data were tested for normality using the Kolmogorov–Smirnov test, and for homogeneity of variance using Levene's test, and transformed in case of non–conformity.

Results

The overall mean water quality parameters (temperature = 29.65 ± 0.06°C; salinity = 34.1 ± 0.03 g/L; DO = 6.85 ± 0.12 mg/L; total ammonia nitrogen = 0.35 ± 0.017 mg/L; nitrite-nitrogen = 0.43 ± 0.12 mg/L; and pH = 8.27 ± 0.24), were observed for all treatments. The values of DO were significantly decreased with increased levels of blood meal inclusion. The lowest value of 4.83 ± 0.20 and 5.07 ± 0.10 were observed at BML 45% and FBML45% respectively, while levels of pH and ammonia increased with an increase of both FBML and BML replacement levels in all treatments. These were however within acceptable ranges for pompano production.

The effects of dietary treatments can be seen in Table 2 and 3 which displays the weight gain over the twelve week study. Fish grew from an average mean initial weight of 10.98 ±0.63g to a final weight of 52.63±0.74 g for fish fed the fishmeal control diet (FM), 78.71±2.10 g for fish fed FBML diets, and 57.27±1.12 g for fish fed

Table 2. Weight gain, specific growth rate, feed conversion ratio, protein efficiency ratio and survival of juvenile *T. blochii* fed the experimental diets (FBML) for 12 weeks.

	Fermented feed levels					
Parameters	**0**	**5%**	**15%**	**25%**	**35%**	**45%**
IBW (g)	10.20±0.3^{a}	10.6±0.43^{a}	9.90±0.56^{a}	11.21±2.01^{ab}	10.26±0.15^{a}	11.09±0.17^{ab}
FBW (g)	52.63±0.74^{a}	76.3±7.15^{b}	83.96±4.1^{c}	82.56±5.6^{c}	88.06±4.92^{d}	62.70±4.32^{e}
TWG (g)	42.43±0.44^{a}	65.70±6.72^{b}	74.06±3.54^{c}	71.35±3.59^{c}	77.80±4.77^{d}	51.61±4.15^{e}
SGR (% day^{-1})	3.03±0.02^{a}	3.29±0.07^{a}	3.25±0.03^{a}	3.22±0.21^{a}	3.27±0.12^{a}	2.99±0.1^{a}
FCR	1.67±0.004a	1.62±0.01^{a}	1.46±0.004^{b}	1.47±0.03^{bc}	1.14±0.01^{d}	1.17±0.01^{e}
PER	1.32±0.003^{a}	1.36±0.009^{a}	1.51±0.004^{b}	1.50±0.03^{b}	1.94±0.02^{bc}	1.89±0.02^{bc}
SR (%)	96^{a}	97^{a}	99^{a}	99^{a}	97^{a}	96^{a}

$^{a, b, c}$ Treatment means within the same row with different superscript letters are significantly different (P < 0.05)

BML diets. The average Specific Growth Rate (SGR%) was directly proportional to increased blood meal inclusion levels for both fermented and unfermented diets to 35% levels, and dramatically decreased at 45% inclusion. The lowest value was observed at 45% diets (2.99±0.1 for fermented, and 2.80±0.14 for unfermented diets), and the highest value was recorded at 35% blood meal inclusion levels (3.27±0.12 and 3.11±0.04), for fermented and unfermented diets respectively. The feed conversion ratio (FCR) from fermented diets increased with a decrease in fish meal levels and the highest value recorded was at 35% blood meal inclusion (1.14±0.01) and poor performance was observed at 45%, with a value below control diets (1.17±0.01). The unfermented diets indicate the poor FCR value at all levels compared to the control diets (Tables 2 and 3).

The actual feed consumption was similar in all groups; none of the feeds was specifically preferred or ignored, with consequent similar protein efficiency ratios between experimental treatments (BML), while for FBML the protein efficiency increased with increased levels. The average cumulative mortality during the experiment was less than 5% for both fermented and unfermented blood meals diets (Table 2 and 3). The growth performance of *T. blochii* showed negative allometric growth in all three of the selected treatments (FBML 35, BML 35 and FM control), with the coefficient of regression "b" values ranging from 2.1 to 2.23 (Figs 1, 2 and 3).The determination coefficients (R^2) ranged from 0.88-0.85. The regression analyses showed strong correlation between fish weights and lengths at all stocking densities. Also, the correlation analyses were significant (r = 0.96, p< 0.01) and the two

Table 3. Weight gain, specific growth rate, feed conversion ratio, protein efficiency ratio and survival of juvenile *T. blochii* fed the experimental diets (BML) for 12 weeks.

	Un-Fermented feed levels					
Parameters	**0**	**5**	**15**	**25**	**35**	**45**
IBW (g)	10.20±0.3^{a}	10.56±0.94^{ab}	11.90±0.37^{bc}	12.30±2.47^{c}	12.33±0.84^{c}	10.33±0.33^{a}
FBW (g)	52.63±0.74^{ab}	55.60±4.90^{b}	58.30±1.18^{b}	59.50±2.99^{b}	67.33±2.74^{c}	45.66±4.66^{a}
TWG (g)	42.43±0.44^{ab}	45.04±3.96^{b}	46.40±0.81^{b}	47.20±0.52^{b}	55.00±1.90^{c}	35.33±4.33^{a}
SGR (%)	3.03±0.02^{a}	3.06±0.10^{a}	2.95±0.06^{a}	2.99±0.23^{a}	3.11±0.14^{a}	2.80±0.14^{a}
FCR	1.67±0.004^{a}	1.66±0.01^{a}	1.68±0.013^{a}	1.68±0.05^{a}	1.65±0.02^{a}	1.72±0.03^{a}
PER	1.32±0.003^{a}	1.33±0.01^{a}	1.31±0.01^{a}	1.31±0.03^{a}	1.34±0.02^{a}	1.29±0.02^{a}
SR (%)	96^{a}	98.6^{a}	96^{a}	98^{a}	96^{a}	97^{a}

$^{a, b, c}$ Treatment means within the same row with different superscript letters are significantly different (P < 0.05)

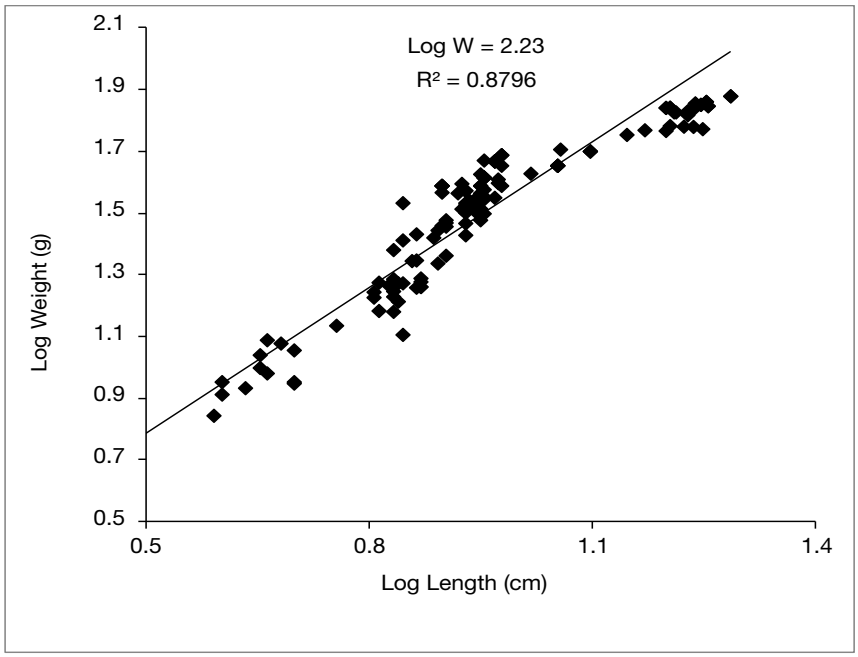

Figure1. Length–weight relationship of *T.blochii* fed FBML 35% for the 12 week feeding trail.

way analysis of variances indicated that there were no significant differences in length-weight performances between the three selected diets of FBML 35, BML 35 and FM control ($p< 0.057$). The growth condition factor (K) value showed marginally similar conditions (1.25, 1.32 and 1.44) from FBML 35, BML 35, and FM control, respectively. The "K" values did not differ significantly among salinity treatments.

The proximate chemical composition of whole-body analyses showed significant differences (Table 4). Moisture, crude protein, crude lipid and ash content of fish fed FM as a control diet were significantly differently compared with the experimental diets (FBML/BML), respectively. The amount of moisture and crude protein show a negative correlation with increased replacement levels of both FBML and BML, while ash and crude lipid contents significantly increased with increased blood meal substitute levels. The highest ash content was recorded in the FBML diet (3.17 ± 0.01) while the highest crude lipid was observed in fish feed BML diets (13.01 ± 0.01). Proximate composition of all experimental diets was very similar, with protein ranging from 45% to 49%, and total lipid values between 11.62% and 12.30%.

The results of the economic evaluation indicated that the incorporation of fermented and unfermented blood meal at appropriate levels as a substitute to fish meal decreased feed costs, leading to a better economic conversion ratio. Costs of 1 kg gain in weight were reduced by 18.2% and 11.6% compared to 3.3% for the control diet. Economical profit index (EPI) revealed that FBML and BML diets presented best economic viability, considering both fish sale price and cost of diets, although no significant differences were found between the treatments.

Discussion

The results from the present study indicate that replacement of fish meal with fermented and unfermented blood is possible. The findings demonstrate that replacement of up to 35% fish meal protein with processed and unprocessed blood meal allowed growth rates similar to, or better than, those exhibited by the control group. The juvenile pompano readily accepted the diets at all levels of fish meal replacement by fermented and unfermented blood meals, as shown by the high feed conversion ratios, specific growth rate, and protein efficient ratios (Tables 2, 3). Similar results were reported for other species including juvenile red snapper *Lutjanus argentimaculatus*, where fish protein was replaced with blood meal up to 23% without negative effects on growth performance (Lee *et al.,* 2001), and 40-50% fish meal replacement levels were reported in the diet of seabream, S*parus aurata* (Davies *et al.,* 1991). In addition, 75-100% fish meal replacement with blood meal was reported to be successful in juvenile grouper, *Epinephelus coioides*, and rainbow trout, *Oncorhynchus mykiss* (Millamena, 2002; Lu *et al.,* 2015). Despite the successful fishmeal replacement by blood meal in various aquaculture diets, some species such

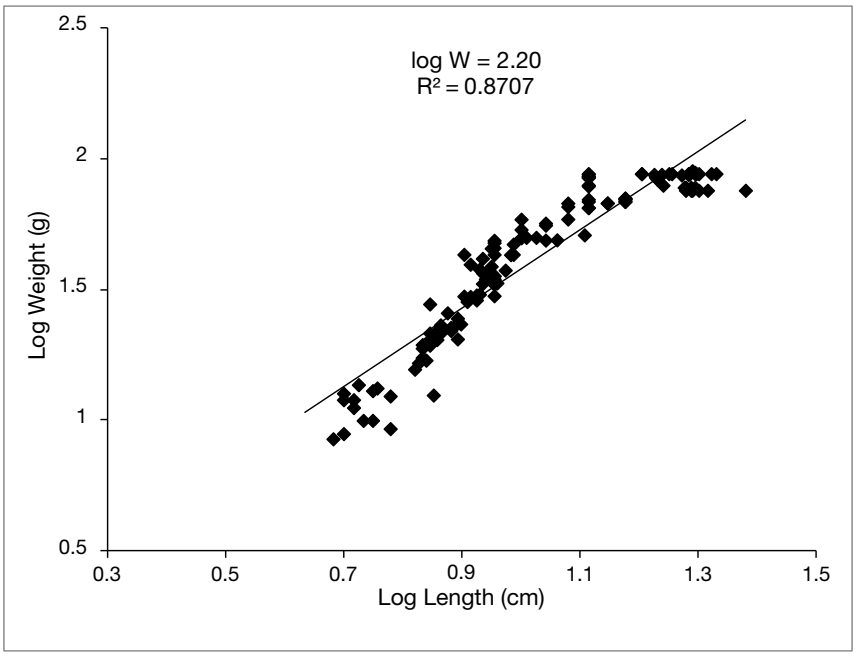

Figure 2. Length–weight relationship of *T.blochii* fee BML 35% for the 12 week feeding trail.

as the Murray cod, *Maccullochella peelii peelii*, and rainbow trout, express negative growth responses with high mortalities when fed diets with increased blood meals inclusion levels (Abery *et al.,* 2002; Bahrevar & Faghani, 2015). In the present study fish survival was not affected by increasing blood meal inclusion levels. These results concur with findings reported by Millamena (2002), Ribeiro *et al*. (2011), and Bahrevar & Faghani (2015). The overall growth performances indicate that fish fed fermented blood meal as a substitute for fish meal attained higher weight gain than un-fermented and control diets. The differences may be related to the processing levels of the blood meal used (Barnes *et al.,* 2012; Dedeke *et al.,* 2013). The reduced weight gain, lower daily growth rates and feed conversion ratio observed in fish fed more than 45% blood meal inclusion levels was possibly related to deficiencies in essential nutrients as well as low palatability and digestibility of blood meal diets (Ribeiro *et al.,* 2011; Burr *et al.,* 2012; Siddika *et al.,* 2012; Bahrevar & Faghani, 2015).

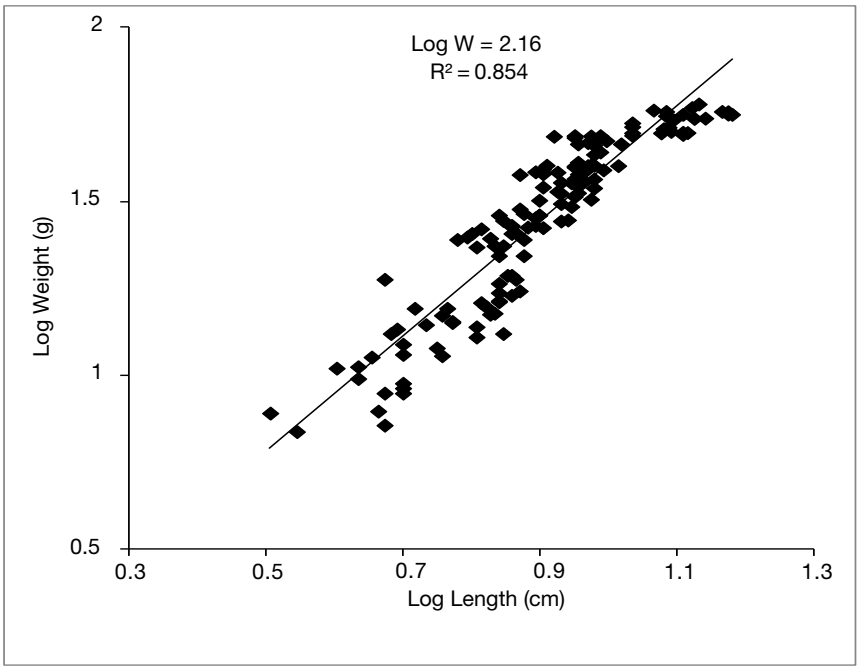

Figure 3. Length–weight relationship of *T.blochii* fed FML for the 12 week feeding trail.

Table 4. Carcass proximate composition of *T. blochii* in the 12-week feeding trial. Fermented feed levels.

Ingredients %	0	5	15	25	35	45
Moisture	69.32± 0.01^{b}	69.01± 0.02^{b}	68.09± 0.01^{b}	67.83± 0.11^{bc}	67.51 ± 0.01^{bc}	65.01± 0.01^{a}
Crude Protein	17.45 ± 0.01^{c}	17.12 ± 0.02^{c}	16.91 ± 0.11^{c}	16.71 ± 0.03^{c}	16.20 ± 0.21^{b}	15.08 ± 0.01^{a}
Crude Lipid	11.9 ± 0.03^{a}	12.02 ± 0.02^{ab}	11.89 ± 0.01^{a}	12.43 ± 0.01^{ab}	12.51 ± 0.03^{bc}	13.01 ± 0.02^{c}
Ash	2.45 ± 0.01^{a}	2.73 ± 0.01^{ab}	2.98 ± 0.02^{ab}	3.06 ± 0.01^{b}	3.17 ± 0.01^{b}	3.69 ± 0.01^{c}

$^{a, b, c}$ Treatment means within the same row with different superscript letters are significantly different (P < 0.05)

Table 5. Carcass proximate composition of *T. blochii* in the 12-week feeding trial. Unfermented feed levels.

Ingredients %	0	5	15	25	35	45
Moisture	69.32± 0.01^{c}	69.41± 0.03^{c}	69.12± 0.02^{c}	68.74± 0.01^{bc}	67.51 ± 0.01^{ab}	67.00± 0.01^{a}
Crude Protein	17.45 ± 0.01^{c}	17.50 ± 0.01^{c}	17.39 ± 0.21^{c}	16.52 ± 0.01^{bc}	16.20 ± 0.21^{ab}	15.72 ± 0.02^{a}
Crude Lipid	11.9 ± 0.03^{a}	11.92 ± 0.01^{a}	12.64 ± 0.01^{ab}	12.49 ± 0.02^{ab}	12.51 ± 0.03^{ab}	13.61 ± 0.01^{b}
Ash	2.45 ± 0.01^{a}	2.97 ± 0.01^{b}	3.11 ± 0.02^{bc}	3.16 ± 0.02^{bc}	3.17 ± 0.03^{bc}	3.91 ± 0.01^{c}

Fish length–weight relationship assessment between three selected replacements levels of FBML 35%, BML 35% and FM control diets revealed that in all treatmenst growth performance was negative allomentric with *b* values of 2.23, 2.20 and 2.16, respectively. The present findings concur with previous observation on pompano species including the oval pompano (*Trachinotus ovatus*) with *b*–values ranging between 2.52 and 2.77 (Guo *et al.,* 2014; Nan–Zhang *et al.,* 2016), *Trichinotus draco* and *T. avatus* with b values of 2.83 and 2.96 respectively (Morato *et al.*, 2001; Morey *et al.*, 2003). In contrast to this, a positive allometric trend was reported for *Trachinotus radiatus* with a b value of 3.2 (Morey *et al.*, 2003). The condition factors for *T. blochii* for both selected feeding treatments were greater than 1 with 'K' values ranging from 1.25 to 1.44. Similar observations of K values were reported for juvenile *T. blochii* and *T. marginatus* cultured under different conditions and feeding regimes, with values ranging between 1.56 to 1.9 (Cunha *et al.,* 2013; Jayakumar *et al.,* 2014). The K values recorded from the present study were comparatively lower than those obtained by Guo *et al*. (2014) and Nan-Zhang *et al*. (2016) for premature *T. ovatus* (3.31 to 3.79 and 11.47 to 14.31, respectively). The observed variation in length-weight relationship and K values in the present study might be attributed to a difference in geographic location, sample size, species, size, and feeding quality (Mommsen, 1998; Anani *et al.,* 2010).

Regarding proximate body composition, the present results reveal that an increase in blood meal contents (fermented and unfermented) in *T. blochii* diets results in significantly increased lipid and ash contents, while moisture contents and crude protein significantly decreased after 35 % blood meal inclusion levels (Tables 4, 5). Similar observations were made on the diet of gibel carp, *Carassius auratus gibelio*, when fish meal was replaced by blood meal at the level of 500 g kg^{-1} (50%). It was reported that the crude protein

Table 6. Economic parameters of *T. blochii* in the 12-week feeding trial.

	Diets		
	FML	FBML	BML
Price Index	1.1	1.14	1
ECR	1.69	1.72	1.16
EPI	0.62	0.63	0.65
Relative ECR %	3.3	11.6	18.2

Calculated from following price of the ingredients (June 2016): Fish meal = 3.0 USD kg^{-1}; Blood meal = 0.50 USD kg^{-1}; Corn meal = 1.0 USD kg^{-1}

content, apparent dry matter digestibility and gross energy were significantly decreased (Yang *et al.,* 2004). Moreover, the findings of Lee *et al*. (2001) demonstrate that an increase of crude protein content in carcasses of juvenile red snapper, *L. argentimaculatus*, related to the increased inclusion level of mixtures of animal by-products in their diet. These findings slightly differ with the observation of a significant difference in the final whole body proximate composition of fingerling rainbow trout, *O. mykiss*, fed a diet with different blood meal inclusion levels, where an increase in moisture content and decrease in ash and lipid contents was reported. Similar findings of a decrease in ash, and increase in lipid, protein and moisture contents, were also reported from carcass composition of Gilthead Seabream (*S. aurata*) fed diets with different levels of blood meal inclusion (Nogueira *et al.,* 2012). Moreover, no significant effects of the fish meal replacement with rendered animal protein were observed on carcasses composition of red sea bream (Takagi *et al*., 2000), grouper species (Shapawai *et al.,* 2007; Gunben *et al.,* 2014), rainbow trout (Bureau *et al.,* 1999), gilthead seabream (Robaina *et al.,* 1997) and European Catfish, *Silurus glanis* (Kumar *et al.,* 2015). In this study, an increase in ash and lipid content with increasing levels of FBML and BML meal was reflected in the proximate analysis of the diets. The economical profit index (EPI) revealed that FBML and BML diets presented best economic viability, considering both fish sale price and cost of diets (Table 6), although no significant differences were found between the treatments. Similar results have been reported when levels of blood have been used in diets of gilthead Seabream, *Sparus aurata* (Nogueira *et al.,* 2012).

Conclusion

Formulated aquaculture feeds are often high in protein and fat, and the bulk of these are generally provided by fish meal and fish oil. Because of their high cost and foreseeable long-term supply problems, a progressive increase in the use of economical protein and lipid sources in aquaculture feeds is inevitable. Feed manufacturers consequently require information on the nutritive value of various alternative protein and lipid sources, such as blood meal.

Fish meal replacement with fermented and unfermented blood meal diets showed promising results for cultured silver pompano, *T. blochii* (Lacépède, 1801). The results from FCR, survival rate, the good growth indicators, and good economic returns, justify the need to commercialize the technology for pompano culture, utilizing locally available sources of protein. Pompano culture could serve as a livelihood for fisher folk and will add to the fish production of the region.

Acknowledgements

We would like to express sincere gratitude to the staff of the Institute of Marine Sciences, University of Dar es Salaam, thanks to the Department of Fisheries Development – Zanzibar, and WIOMSA for their support. The study was fully financed by SIDA via the Institute of Marine Sciences Programme, and by WIOMSA through a MARG I Grant.

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The food and feeding habits of the Delagoa threadfin bream, *Nemipterus bipunctatus* (Valenciennes, 1830), from the coastal waters around Dar es Salaam, Tanzania

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Abstract

Nemipterus bipunctatus is among the Nemipterids that support artisanal fisheries throughout most of the Western Indian Ocean (WIO) region. Despite its economic importance, information on food and feeding habits is poorly known in the region. Feeding habit was examined with respect to size, sex, maturity stages of the predator, and season. The food preference for *N. bipunctatus* was determined using Index of Relative Importance (IRI). Crustaceans were the main prey group accounting for more than 40% IRI of the total food ingested with crabs being the most dominant prey item in the group. Fish ranked as the second prey group accounting for 32.1 % IRI of the total food consumed. Meiofauna, bivalves, miscellaneous and cephalopods made up the rest of the diet. Significantly higher mean number of major prey categories were encountered in *N. bipunctatus* stomachs during the southeast monsoon as compared to during the northeast monsoon (two way contingency table analysis test, χ2-test, df=3, p< 0.001). An ontogenic diet shift study revealed that meiofauna, cephalopods, and bivalves groups had higher contributions in the diet of smaller *N. bipunctatus* of total length (TL) 9.5-11.5 cm, to 13.6- 15.5cm; the values for this group ranged from 49.7% IRI to 0.4% IRI respectively. Fish prey contributed significantly to the diet of larger individuals of this species, ranging from 0% in small fish (9.6-11.5cm TL) to 77.0% in large fish (> 21.5cm TL). Crustaceans contributed a small proportion to the diet of this species in the upper size classes with this category almost constant in the middle and lower size classes. It was therefore concluded that the main food of *N. bipunctatus* is crustaceans. However, an ontogenic shift in diet occurs, with meiofauna, bivalves and cephalopods preferred by smaller size classes, and fish by larger size classes.

Keywords: *Nemipterus bipunctatus,* Main prey groups, fish size, diet composition, IRI

Introduction

Feeding is one of the most important activities of organisms. Basic functions such as growth, development and reproduction of an organism take place at the expense of the energy acquired through food (Nikolsky, 1963). Studies of feeding behavior of fishes are very important whenever fish stock assessment and ecosystem modeling are required. For instance, approaches for multi-species virtual population analysis (Sparre, 1991; Bulgakova *et al*., 2001) and the ECOPATH II ecosystem model (Christensen & Pauly, 1992) require information on the dietary composition of fishes. Besides, information on feeding ecology is important to understand the functional role of the fish within their ecosystems (Hajisamae *et al*., 2003; Abdel-Aziz & Gharib, 2007).

Fishes show diverse adaptations in their feeding behaviour and are therefore classified into different trophic categories. One of these behaviours is predation, being an essential part of interaction among species, which has a profound influence on population dynamics and is a basic element of biological competition (Sainsbury, 1982). Without knowledge of the food requirements, feeding behaviour pattern, and predator-prey relationships, it is not possible to

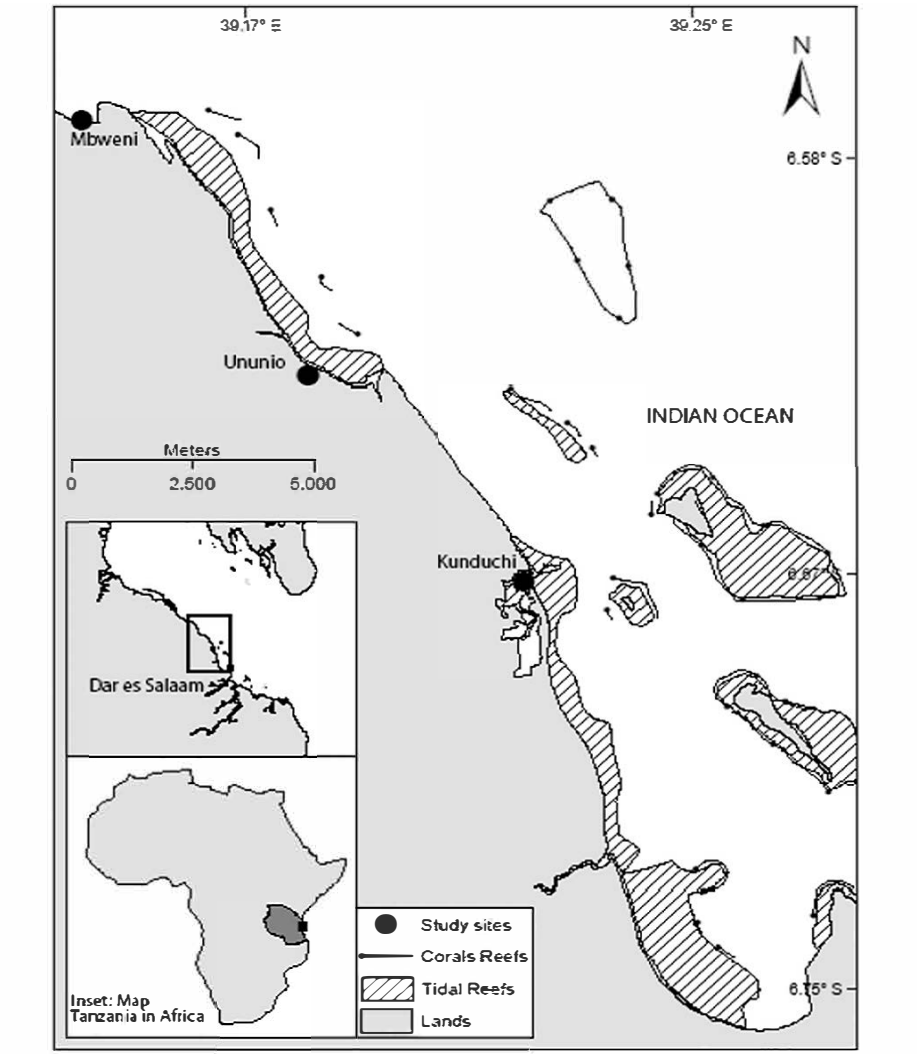

Figure 1. Location of the study sites along the Dar-es-Salaam coast.

understand the predicted changes that can result from any natural or anthropogenic intervention (Hajisamae *et al*., 2006). Different sizes of fish belonging to the same species may feed on similar diets, however they tend to choose or prefer particular dietary items depending on size, sex stage of maturity, and prey availability. The dietary preferences among individuals of the same species often occur due to differential prey capture abilities to take diverse morphological and behavioural variations of prey (Sudheesan *et al.*, 2009). The 'where', 'when' and 'what' of dietary choice is subject to feeding habits based on foraging theory (Hyslop, 1980), where a fish always choses the most profitable prey (Gerking, 1994). Stomach content analysis can be a useful method to use when investigating what food a predator mainly depends on, its ecology and foraging behaviour (Clarke & Kristensen, 1980).

Several studies have investigated the food and feeding habits of large pelagic fishes from the Western Indian Ocean (WIO). For instance, Potier *et al*. (2007), Malone *et al*. (2011) and Roger (1994) studied the diet of large pelagics (lancetfish, swordfish, yellowfin tuna, Wahoo, Skipjack tuna, dolphin fish) from the WIO. However, very little is known about the feeding habits and diet shifts of small demersal species in the WIO. Ndaro & Olafsson (1995) studied the feeding habits of *Gerres oyena* in a tropical lagoon in Zanzibar; this is among the few studies that have been conducted in the region. The present study aims at determining the diet composition (major trophic groups) of *N. bipunctatus* and its intra-population variation. This species belongs to the family Nemipteridae, distributed throughout the Indian Ocean and abundant in coastal waters (Russell, 1990). The species support a large artisanal fishery in Tanzania and the WIO region as a whole. Findings of this study will allow for better understanding of the feeding behaviour and diet shifts of this species, and may be useful for stock and ecosystem-level analyses.

Materials and methods

Study sites

The fieldwork was conducted at three fish landing sites (Kunduchi, Ununio, Mbweni) located on the eastern coast of Tanzania (Fig. 1). These landing sites were chosen because they are some of the most active in Tanzania and have high fish landings. Landings from these sites were considered more representative and likely to capture different sizes of *N. bipunctatus*. Fishing activities at these landing sites are normally concentrated within the near shore reef lagoons as fishermen infrequently venture beyond the outer reef due to unsuitable fishing crafts.

Sampling methodology

Monthly fish samples were randomly collected from the artisanal hand-line fishery from January to December, 2012. The fishers used hand-lines (with hooks of sizes ranging between number 12 and 14) to catch this species. Upon arrival of the fishers at the landing sites after 4 to 5 fishing hours, Nemipterids were collected from the catches and identified to species level using Bianchi (1985). Identified specimens were kept chilled in boxes to slow down the bacterial digestion process until further analysis.

Diet

The stomachs of fish of different sizes were split open using scissors to remove all food items. Food items were identified following the description given in the FAO species identification key (Bianchi, 1985). Various food items were separated, identified to genus level, and whenever possible to the species level, and later counted under their respective groups. Methods defined by Hyslop (1980) were used to determine: (i) percentage numerical abundance (% N), indicated by the number of individuals of each prey category recorded for all stomachs expressed as a percentage of the total number recorded in all food categories; (ii) percentage weight (% W), indicated by the volume of individuals of each prey type in all stomachs expressed as a percentage of the total volume of food items measured in all stomachs; and (iii) percentage frequency of occurrence (% FO), indicated by the number of stomachs in which each prey item had occurred and expressed as a percentage of the total number of stomachs examined. The Index of Relative Importance (IRI) was determined by linear combination of % N, % W and % FO as single numerical values expressed according to Pinkas *et al.* (1971), Cailliet & Ebeling (1990) and Vivekanandan (2001) as follows:

$IRI = (C_N + C_W) \times FO$

The index was expressed as a percentage for each food group as follows:

$\%IRI = (IRI / \sum IRI) \times 100$

Sex determination and classification of maturity class

The ventricle of the fishes was split open using a pair of scissors to determine the sex and maturity stages as described by Ntiba & Jaccarini (1990). The maturity class for both male and female *N. bipunctatus* was determined macroscopically. The classification of maturity stages in male specimens was mainly based on the shape of the testes and colour of the milt from testes. In females, maturity stages were classified based on the shape of the ovary, and size and colour of the oocytes. For both sexes maturity stages were classified (IIa = developing virgin, IIb = resting and recovering, III= early developing, IV = late developing, V = ripe and running, and VI = spent). Stages IIa were IIb were considered immature, and stages III, IV and V were considered mature and most important in reproduction.

Determination of the quantity of prey ingested by *N. bipunctatus*

The threadfin breams are known to feed on a variety of food categories, therefore determination of the quantity of prey items ingested was done by counting individual items for each prey category encountered in the fish stomach. Multiple fragments of individual items (for instance fish bones and scales) were counted as different individuals per stomach each time they were encountered regardless of being in the same prey category.

Comparison of diet according to size, maturity class and sex of fish

The mean number of prey items in each size class was calculated to determine the relationship between *N. bipunctatus* size and the quantity of prey items ingested. However, to test for the differences in the quantity of prey items consumed between mature and immature, male and female *N. bipunctatus,* the mean number of prey items encountered in their stomachs was used in statistical comparison.

Statistical analysis

Spearman rank correlation (r_s) was used to test for the relationship between fish size and the mean number of food items ingested. The Mann-Whitney *U*- test (MWU) was used to test for difference in mean number of food items in the diet of immature and mature fishes. The difference in the mean number of food items consumed by mature male and female

Table 1. Percentage IRI (% IRI), Index of Relative Importance (IRI), and percentages of Number (NO), Frequency (FO) and Weight (WO) of different prey groups and items encountered in *N. bipunctatus* stomachs.

Prey items	%NO	%FO	%WO	IRI	% IRI
Crustaceans					
Penaeid prawns	6.92	7.15	8.98	113.74	12.06
Crabs	10.50	8.90	14.71	224.37	23.79
Squilla	3.67	8.72	5.90	83.48	8.85
Crustaceans total	21.10	24.77	29.59	421.59	44.69
Fish					
Sardinella spp.	8.28	4.43	8.50	74.29	7.88
Triuchurus spp.	0.68	0.82	1.45	1.75	0.19
Stolephorus spp.	11.02	5.84	10.91	128.12	13.58
Cynoglossus spp.	5.01	4.80	6.95	57.48	6.09
Caranx spp.	1.04	1.48	1.93	4.41	0.47
Thrysa spp.	3.58	3.76	5.70	34.91	3.70
Nemipteridae	0.17	0.22	0.63	0.18	0.02
Siganus spp.	0.02	0.02	0.12	0.00	0.00
Trachinocephalus myops	0.62	0.86	1.03	1.43	0.15
R. kanagurta	0.05	0.04	0.11	0.01	0.00
Balistidae	0.20	0.27	0.34	0.14	0.02
Lethrinus spp.	0.11	0.15	0.29	0.06	0.01
Fish total	30.78	22.71	37.96	302.77	32.10
Meiofauna					
Nematodes	0.06	0.29	0.19	0.07	0.01
Annelids	4.68	5.53	3.88	47.40	5.03
Copepods	1.09	0.11	0.32	0.16	0.02
Small shrimps	2.05	14.97	1.83	58.13	6.16
Meiofauna total	7.89	20.90	6.23	105.76	11.21
Bivalves					
Mussels	6.11	5.87	9.71	92.84	9.84
Bivalves total	6.1	5.9	9.7	92.8	9.84
Miscellaneous					
Fish scales	2.75	2.15	3.56	13.56	1.44
Fish bones	0.17	0.24	0.64	0.20	0.02
Miscellaneous total	2.93	2.39	4.20	13.76	1.46
Cephalopods					
Squids	0.31	10.14	0.13	4.50	0.48
Octopus	0.34	4.05	0.16	2.05	0.22
Cephalopods total	0.65	14.19	0.30	6.55	0.69

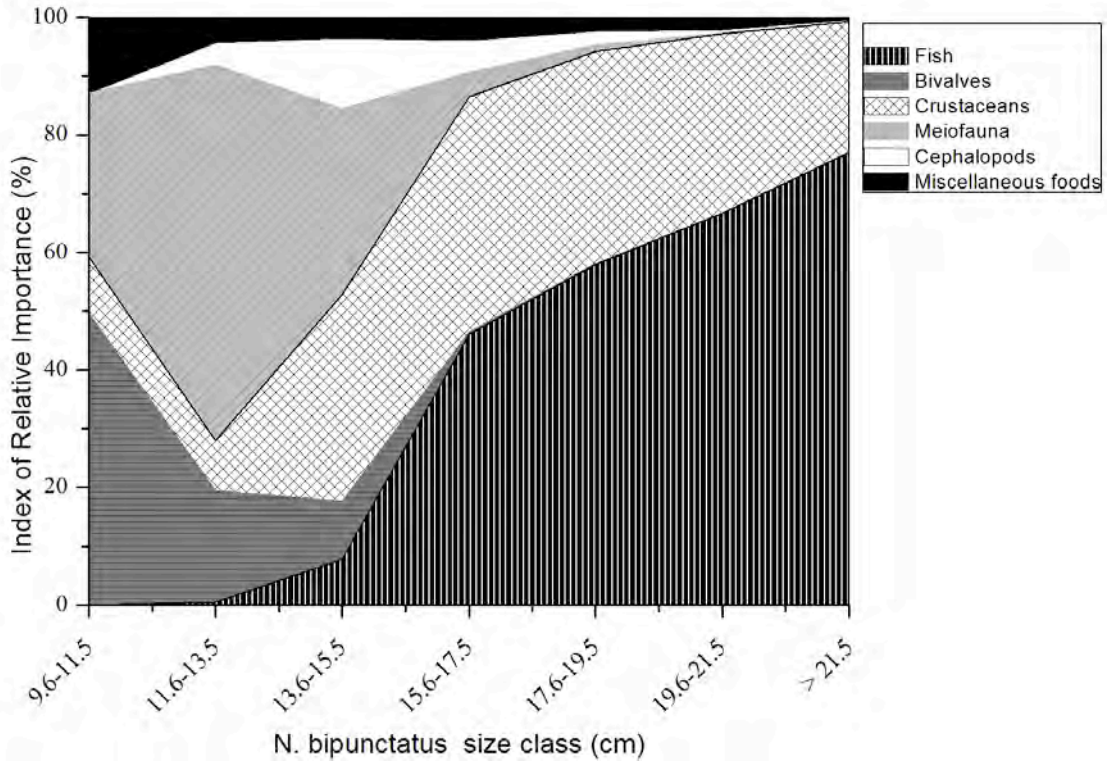

Figure 2. The percentage Index of Relative Importance (% IRI) of food items in the diet of *N. bipunctatus* by length class.

N. bipunctatus was examined using the *t*-test. Two-way contingency table analyses using the Chi- square test were used to test the difference in the mean number of major prey categories between seasons. All statistical data analyses were performed using SPSS analytical software. A 0.05 significance level was used for all tests.

Results

Diet composition

Six principal food groups were observed in the diet of *N. bipunctatus*. These included 12 fish species (*Stolephorus* spp, *Triuchurus* spp, *Sardinella* spp, *Cynoglossus* spp, *Caranx* spp, *Thryssa* spp, *Nemipterid* spp, *Rastrelliger kanagurta*, Balistidae, *Lethrinus* spp, *Siganus* spp, *Trachinocephalus myops*), 2 cephalopods (Squid and Octopus), 3 crustaceans (penaeid prawns, crabs and Squilla), 1 bivalve (mussels), 4 meiofauna (free living nematodes, annelids, copepods and small shrimps) and miscellaneous foods (fish scales and bones).

A total of 1367 *N. bipunctatus* specimens of 9.5-21.5 cm were examined; 20.5% of these specimens had empty stomachs. Prey groups and food items were encountered in 1087 stomachs of *N. bipunctatus* and are shown in Table 1. Crustaceans were the main prey group accounting for more than 40% IRI of the total food ingested. In this group, crabs were the main prey item with 23.8 % IRI, followed by penaeid prawns accounting for 12.1 % IRI. The penaeid prawns were represented by *Penaeus indicus* and *Penaeus semisulcatus*. Fish ranked as the second prey group accounting for 32.1 % IRI of the total food consumed, and *Stolephorus* spp. was the most dominant prey in the group with 13.6 % IRI. Meiofauna formed the third most important food element of *N. bipunctatus*. The composition of this prey category to the total food ingested was 11.2% IRI, with annelids being the main prey items (5% IRI) in the group. Although bivalves were represented by only mussels, they made a remarkable contribution to the diet of this species and were ranked fourth after Meiofauna. Mussels were the only prey item in this category accounting for 9.8% IRI of the total amount of foods encountered in stomachs of *N. bipunctatus*. Miscellaneous food and cephalopods contributed very minor proportions; they formed only 1.5% IRI and 0.7% IRI of all prey categories encountered in stomachs of *N. bipunctatus*, respectively. Moreover, the *t-test* showed variation among the four key prey categories contained in the stomachs of male and female *N. bipunctatus*. There was a significant difference in consumption of crustacean prey category (t= 4.0, df= 45, $p<0.05$) and bivalve prey category (t=2.4, df=45, $p<0.05$) between males and females. On the other hand, there was no significant difference in consumption of the fish prey

Table 2. Monthly percentage Index of Relative Importance (% IRI) of different food items of *N. bipunctatus* during 2012.

Prey items	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fishes												
Sardinella spp.	9.53	9.01	17.4	12.4	13.52	12.3	14.7	14.1	11.90	10.96	7.25	12.20
Triuchurus spp.	2.20	0.01	0.12	0.11	0.15	-	-	-	0.19	0.15	0.06	0.03
Stolephorus spp.	16.37	20.12	26.9	21.6	15.53	21.8	22	21.5	19.44	22.25	26.5	22.29
Cynoglossus spp.	4.00	0.26	2.03	1.45	2.46	0.21	5.86	1.29	0.88	2.69	0.64	4.14
Caranx spp.	-	0.49	0.12	0.51	0.1	0.04	0.14	1.43	0.14	0.40	0.01	0.04
Thrysa spp.	5.97	3.72	0.71	0.32	2.29	2.83	2.05	0.92	0.31	1.12	0.16	1.94
Nemipteridae	-	0.01	0.02	-	0.00	-	-	0.00	0.04	0.46		0.02
Siganus spp.	-	-	-	-	-	-	-	-	0.53	-	-	-
T. myops	-	2.01	-	0.95	0.88	0	0.24	0.07	0.04	0.12		0.11
R. kanagurta	-		-	-	-	-	-	-	0.01	-	-	-
Balistidae	-	0.02	-	0.03	0	0.21	-	0.00	0.02	0.00	-	-
Lethrinus spp.	-	0.01	-	0.04	0.01	0.00	-	-	0.00	0.00	-	-
Total	38.07	35.7	47.3	37.4	34.94	37.4	45	39.3	33.5	38.15	34.6	40.77
Crustaceans												
Penaeid prawns	2.19	1.03	0.02	0.56	0.95	0.36	0.5	0.06	0.47	0.66	0.22	1.21
Crabs	46.1	56.8	47.4	56.4	56.96	56.8	51.6	52.5	61.42	57.8	42.10	55.1
Squilla	1.04	0.16	0.26	0.08	0.16	0.2	0.02	0.00	0.59	0.42	0.09	0.17
Total	49.4	58	47.6	57	58.07	57.3	52.1	52.58	62.48	58.9	42.40	56.5
Meiofauna												
Nematodes	0.6	-	0.04	-	0.02	0.02	-	-	-	-	-	-
Annelids	3.76		0.13	0.58	0.65	0.54	0.27	1.55	0.38	0.44	0.47	0.01
Copepods	0.52	-	-	-	-	-	-	-	-	-	-	-
Small shrimps	0.69	0.01	0.7	1.66	0.32	0.92	0.31	3.28	0.91	0.03	15.4	0.74
Total	5.57	0.01	0.87	2.24	0.99	1.48	0.58	4.83	1.29	0.47	15.9	0.75
Bibalves												
Mussels	3.21	5.30	3.37	1.94	4.95	3.27	1.87	2.13	1.87	2.1	2.43	1.66
Total	3.21	5.30	3.37	1.94	4.95	3.27	1.87	2.13	1.87	2.1	2.43	1.66
Miscellaneous												
Fish scale	-	0.14	0.12	0.18	0.03	0.18	0.04	0.67	0.23	-	-	0.34
Bones	1.18	0.32	0.08	0.37		0.09	-	-	0.08	-	4.69	
Total	1.18	0.46	0.2	0.55	0.03	0.27	0.04	0.67	0.31	-	4.69	0.34
Cephalopods												
Squid	2.2	0.55	0.65	0.81	1.02	0.23	0.4	0.49	0.53	0.41	-	-
Octopus	0.41	0.01	0.01	0.04	0	-	-	-	0.02	-	0.01	0.02
Total	2.61	0.56	0.66	0.85	1.02	0.23	0.4	0.49	0.55	0.41	0.01	0.02

Table 3. Two way contingency table analysis and the Chi-square test of seasonal variation of major prey categories of *N. bipunctatus*.

	Season			
Prey group	**NE**	**SE**	**Nj**	**χ2**
Crustaceans	105	162	267	0.1
Fish	64	118	182	8.8
Meiofauna	73	88	161	13.5
Bivalves	30	47	77	0.0
χ2				22.4

Nj= Mean numbers of preys by seasons **, P < 0.001, df= 3

category (*t*= -1.5, df=45, p=0.2) and meiofauna (*t*=0.9, df=45, p=0.4) between sexes.

Ontogenic diet shifts

Various prey categories in the diet of *N. bipunctatus* of different size classes are shown in Fig. 2. The percentage (% IRI) for fish prey increased while that of meiofauna, bivalves and cephalopods decreased with size of the predator. The % IRI of fish ranged from 0% in *N. bipunctatus* of 9.6-11.5 cm (TL) to 77.0% in *N. bipunctatus* of > 21.5 cm (Fig. 3), while that of meiofauna, bivalves and cephalopods ranged from 49.7% in *N. bipunctatus* of 9.6-11.5 cm to 0.4% in *N. bipunctatus* of > 21.5 cm. The % IRI for crustaceans did not change much with size of *N. bipunctatus*, with their values ranging from 9.6% in fish of 9.6-11.5 cm to 22.3% in fish of > 21.5 cm. It was therefore apparent that *N. bipunctatus* mainly feeds on meiofauna, cephalopods and bivalves at smaller sizes (from 9.5-11.5 cm to 13.6-15.5 cm), and on crustaceans throughout its life cycle at all size classes. However, fishes were observed to be more important in the diet of larger individuals of this species.

Seasonal variation in feeding activity pattern

Analysis of the monthly variation in IRI of prey items in the diet of *N. bipunctatus* is shown in Table 2. Crustaceans were the most important prey category, occurring in the stomach of *N. bipunctatus* in the highest proportions (> 50%) almost every month. Within the crustacean group, crabs formed the main food item of the species in all months. The highest value for crabs was in September (% IRI=61.42) and lowest in November (% IRI= 42.10). Fishes formed the second most important food element of *N. bipunctatus* and were observed throughout the year. *Stolephorus* spp. (*S. commersonii* and *S. indicus*) were the most dominant species in the stomachs of *N. bipunctatus,* with % IRI value ranging from 16.37 (January) to 26.9 (March). Meiofauna

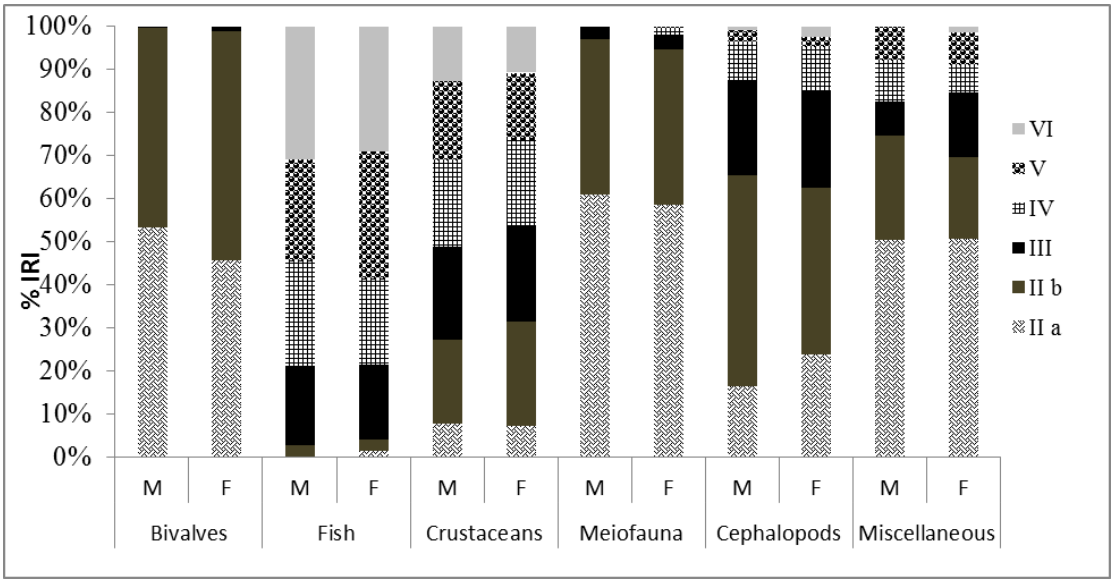

Figure 3. Feeding of *N. bipunctatus* on different prey groups in relation to sex and maturity stage. (M=Male, F= Female)

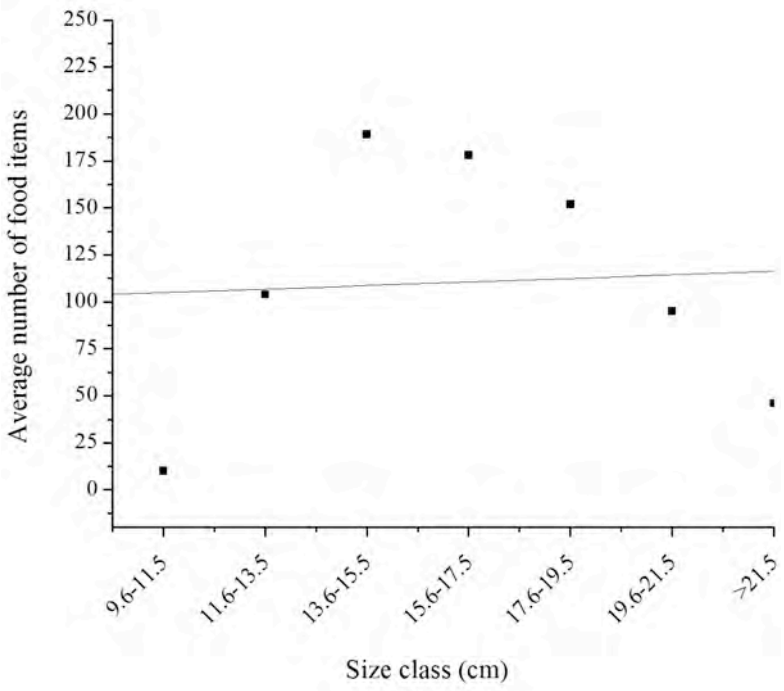

Figure 4. Relationship between body length and mean number of food items in the stomach of *N. bipunctatus.*

ranked third among the food organisms with small shrimps being dominan recording the highest % IRI of 15.40 in November and lowest % IRI of 0.01 in February.

Bivalves ranked as the fourth most important prey category, and were encountered in the diet of *N. bipunctatus* in all months. The group was represented by mussels only and the peak period for this food item was in February (% IRI = 5.30), and the least amount was recorded in December (% IRI = 1.66). Although miscellaneous foods and cephalopods were found in the diet of *N. bipunctatus*, their contributions were very minor, and they were considered as a secondary inclusion in the diet. The highest % IRI in both groups was observed in January, and lowest proportion of diet consumed was recorded in May for meiofauna, and November for cephalopods. Generally, four major prey groups were encountered in the stomach of *N. bipunctatus* as shown in Table 2.

Analysis performed on specimens collected during the northeast (NE) and southeast (SE) monsoon revealed that there was significant seasonal variation in the diet of *N. bipunctatus.* Fishes were the most dominant prey group in both seasons (NE - from November-April, SE - from May-October). Higher proportions of all key prey groups were encountered in *N. bipunctatus* stomachs during the SE monsoon as compared to NE monsoon. Two-way contingency table analysis using the Chi-square test showed that there is a significant difference in the mean number of major prey categories in the stomach of fish between seasons (χ2-test, df=3, p<0.001, Table 2).

Comparison of diet between sexes and maturity stages

Meiofauna, cephalopods, miscellaneous and bivalves were the main dietary items of immature (stages IIa and II b) male and female *N. bipunctatus*. Mature individuals (stages III-VI) of this species consumed a low variety of prey items as compared to immature ones. However, there was no significant difference in consumption of different prey items between males and females in immature and mature individuals (paired sample *t* = test, p> 0.05). Exceptional results were noted for the fish prey category in mature individuals where male *N. bipunctatus* were observed to feed on a larger proportion (% IR) of fish prey than females (*t*-test, p> 0.05) (Fig. 3).

Comparison of diet between size, maturity class and sex

No significant correlation was found between the mean number of food items and size among different size classes of *N. bipunctatus* (Spearman rank correlation (r_s), r = 0.036, N=1,367, p> 0.05; Fig. 4). Mature fish had significantly higher mean numbers of food items in their stomachs (n=4) compared to the immature ones (n=2),

(Mann-Whitney *U*- test = 11.0, p<0.01). However, there was no significant difference between the mean number of food items consumed by mature male (n=4) and female (n=4) *N. bipunctatus* (*t*-test, *t*=0.6, p=0.57).

Discussion

Diet composition and feeding strategy

Generally, *N. bipunctatus* exhibited a benthic carnivorous and opportunistic feeding habit, with crustaceans, particularly crabs, forming the main diet. Other prey groups in the diet included fishes, meiofauna, bivalves, miscellaneous items, and cephalopods. Similar results on the diet composition of *N. bipunctatus* have been reported by Madan & Velayudhan (1984). Sudheesan *et al*., (2009), Raje (2002), Acharya *et al.*, (1994) and Manojkumar *et al.*, (2015) studied the feeding habit and stomach contents of *Nemipterus japonicus* and concluded that this species is a benthic carnivore mainly feeding on crabs. Although *N. bipunctatus* seemed to prefer most benthic crustaceans as has been reported for other nemipterids, it also consumes a broad spectrum of fishes (Manojkumar *et al.,* 2015). The importance of fishes in the diet of *N. bipunctatus* could not be overlooked as they ranked second after crustaceans and more than 12 species were encountered in the stomach of this nemipteridae spp. While the range of prey consumed by *N. bipunctatus* was large, comparatively few prey groups; for instance crustaceans (crabs) and fish (*Stolephorus* spp.) dominated the diet (% IRI) in all months. This indicated that *N. bipunctatus* was either selecting prey or that some prey items were found more frequently than others throughout the year, probably due to seasonal variations which determines their abundance (Manojkumar *et al.*, 2015). Similar findings have been reported by Vivekanandan (2001), Acharya *et al*. (1994) and Rao & Rao (1991), who studied the trophic status of *N. japonicus* in India. Cannibalistic behaviour was also commonly observed in this species as in the case of *N. mersoprion* (Raje, 1996) and *N. japonicus* (Manojkumar *et al.*, 2015; Kuthalingam, 1965).

Ontogenic diet shifts

A comparison of prey groups consumed by different size classes of *N. bipunctatus* showed ontogenic diet shifts. Small sized prey such as meiofauna (copepods, shrimps etc), and bivalves (mussels) were the main prey categories for sub-adult *N. bipunctatus*, later being replaced by different fish species, the secondary prey for larger individuals of this species. On the other hand crustaceans were consumed throughout the life cycle of *N. bipunctatus.* These results signify an important change in feeding strategy in which the diet of smaller individuals comprised a large number of smaller prey while those of larger individuals consisted of fewer, larger prey. As the mouth size severely limits the size of prey which can be ingested (Stickney, 1976), the diet of fish is related to their digestive morphology and mouth structure. As the fish grow the size of the mouth increases proportionately, their swimming capacity is modified, and their energy requirements vary (Stergiou & Fourtouni, 1991; Platell *et al.,* 1998). Thus larger fish have different diet requirements to smaller ones, and attempt to satisfy this by consuming larger prey types. Similar findings on members of the Nemipteridae have been reported elsewhere. For instance, Vivekanandan (2001) reported that *N. japonicus* primarily feeds on crustaceans, diversifies its feeding as it grows, and relies on fish as a secondary prey group when attaining a larger size. Manojkumar (2008) also found the same trend in the feeding habit of *Nemipterus mesoprion* from the Malabar coast.

A change in diet as fish grow is related to complex feeding habits of various fish species. Species may feed at different levels in the food chain at different stages of their life cycle, or change feeding behaviour with age. Similar observations have been also reported in other species; for instance Landry (1997) found that fully adult cod fish are predators on herring but when they are small (< 50 cm) they feed on copepods and other planktonic crustaceans. The observation of changes in feeding habit with age in *Nemipterus* species has been reported previously (Vivekanandan, 2001; Rao & Rao, 1991).

Although the present study revealed that food preference of *N. bipunctatus* changes with size, it should also be kept in mind that food preference of fish is very complex and is subjective to a number of factors including prey or food accessibility and mobility, food abundance, food energy content, food size selection and seasonal changes (Hart & Ison, 1991; Stergiou & Fourtouni, 1991).

Seasonal variation in feeding activity pattern

Monthly variation of prey items in the diet of *N. bipunctatus* showed that crabs from the crustaceans group was the most dominant prey item in every month. An existence of such a wide range of crustaceans, particularly crabs in the stomach of this species has been also reported by Afshari *et al*. (2013), Bakhsh (1994), and Manojkumar (2004) in *N. japonicus.* The dominance or presence of any prey in the diet of fish depends, among other factors, on its frequent availability in the environment. Nikolsky (1963) revealed that the reason for the difference in frequency of food

types in the stomach is related to its frequent availability in the environment. Presumably, this could be a reason for higher contribution of crabs/crustaceans found throughout the year in the diet of *N. bipunctatus*.

Seasonal differences in consumption of the key prey groups were also significant in the present study. Higher preference of crustaceans was observed in both seasons (NE and SE), hence signifying its importance as the main diet for this species (Table 3). Following these observations, presumably *N. bipunctatus* is a selective feeder or tends to capture whatever prey it finds most frequently in its surroundings. Such behaviour is also exhibited in other teleost fishes (Wootton, 1995). The seasonal dominance of crustacean prey in the diet has been reported elsewhere in other *Nemipterus* species; for instance Afshari *et al*. (2013) found this prey group to be the most dominant in the diet of *Nemipterus japonicus* in three seasons (spring, summer and autumn). Higher proportions of all key prey in the stomachs of *N. bipunctatus* recorded in the SE monsoon could be related to seasonal variation which is known to determine their abundance (Manojkumar *et al.*, 2015). Most of the fish collected during the NE monsoon were in advanced stages of sexual maturity with the body cavity fully occupied by ripe mature gonads (personal observation). The reduced feeding activity on the four key prey groups during this time could be an indication of intense spawning along Dar es Salaam coast. It is important to emphasize that the effect of seasonality should always be considered in fish feeding studies, because the temporal changes of biotic and a biotic factors alters the structure of the food web through the year, and as a result the fish often show seasonal diet shifts (Kariman *et al.,* 2009).

This study found that *N. bipunctatus* feeds on a variety of foods in its life cycle, and mainly on crustaceans. However, it exhibited an ontogenic diet shift and consume meiofauna, cephalopods and bivalves at small sizes, and then prefers fish prey at a larger size. Crustaceans are fed on throughout its life cycle at all sizes. Most of what was found in the diet of individuals during this study was of animal origin (fishes, crustaceans and cephalopods) confirming that *N. bipunctatus* is a carnivore.

Acknowledgements

The authors would like to thank the Marine and Coastal Environment Management Project (MACEMP) for funding this study. Thanks are extended to the Tanzania Fisheries Research Institute for logistic help and provision of space for laboratory work.

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Polycyclic aromatic hydrocarbons (PAHs) contamination in coastal mangrove ecosystems of the Zanzibar archipelago

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Abstract

The objective of this study was to determine the levels of polycyclic aromatic hydrocarbons (PAHs) in sediments and crabs in the mangrove ecosystems of Zanzibar. Sediments and crabs from eight sampling sites were analysed for eleven selected PAHs. Samples were extracted with dichloromethane by ultrasonication, cleaned-up using column chromatography, and concentrated using a rotary evaporator. GC-MS was used in the analysis of the samples. In general, all eleven PAHs were detected in crab and sediment samples. Total concentrations of PAHs ranged from 1.70 to 28.66 ng/g fresh weight (fw) in crabs, and from 20.14 to 81.94 ng/g dry weight (dw) in the sediments. The levels of the PAHs are thought to be related mostly to petrogenic and pyrogenic sources from anthropogenic activities. The results from this study demonstrated the existence of PAHs contamination in mangrove ecosystems of Zanzibar, and it is recommended that a PAHs contamination monitoring programme be established.

Keywords: PAHs; crabs; sediments; coastal areas; Tanzania

Introduction

PAHs are among the persistent organic pollutants that are a worldwide environmental problem due to their environmental and health effects such as persistence, carcinogenicity, mutagenicity, and endocrine disrupting effects. Persistence of PAHs in the environment is related with molecular stability and hydrophobicity (Kanaly & Harayama, 2000) and the tendency of bioaccumulation through food chains resulting in adverse effects in living organisms including human beings (Eljarrat & Barcelo, 2003). Thus monitoring, control and mitigation of PAHs is an important endeavour. An increase in human activities related to sea transportation, fuel-based power generation, and the tourism industry along the coast of the Zanzibar islands, has increased PAHs emissions into the environment. The Zanzibar islands receive heavy seasonal rainfall, and the contaminants from various sources including household, vehicles, harbours and fuel stations possibly enter the coastal environment by means of waste discharges, surface runoff and aerial fallout. Monitoring of PAHs contamination in Zanzibar has not been undertaken to date, and this study provides the first information on the concentrations of PAHs in crabs and sediments from the mangrove ecosystems in the coastal areas of the Zanzibar archipelago.

Materials and Methods

Study Areas

The study was carried out in the coastal areas of the Zanzibar Islands (Unguja and Pemba). Two sampling sites were selected in Pemba, namely Ngezi and Wesha, and six in Unguja, located at Bumbwini Makoba, Jozani, Donge Muwanda, Kinazini, Mbweni, and Maruhubi. The locations of the sites are shown in Figs. 1 and 2.

Among the sampling sites, five had high levels of anthropogenic activities, while the remaining three had low levels of anthropogenic activities. Ngezi, which is in the northern part of Pemba Island, is a government protected forest site. At Wesha, there are many anthropogenic activities that are carried out including day-to-day shipping operations, diesel-run

Figure 1. Map showing the location of sampling sites in Pemba Island.

electric power generation, and fuel transfer from tankers into receiving facilities which are often associated with oil spills. Other human activities include the burning of firewood and charcoal, fishing activities, boat/dhow making, and fishing machinery servicing. The coastal area of Wesha also receives contamination from road smelters.

Jozani is located in south west Unguja Island. The Jozani mangroves and wetlands are a government protected forest reserve. Within this area there are low anthropogenic activities. Donge Muwanda is in northern Unguja Island. There are extensive fish processing activities in this area, including smoking and roasting on the beach, which use a lot of firewood. Kinazini mangrove ecosystem is in an urban area of Zanzibar Island. It receives domestic waste and other anthropogenic waste products from Zanzibar town which are discharged directly into the mangrove ecosystem of Kinazini. Marine transportation, car washing, service stations, and boat/dhow making and servicing activities are also carried out in this area.

Maruhubi is in an urban area of Zanzibar Island near Kinazini. Within the coastal area of Maruhubi fuels are combusted and petroleum products are used during boat/dhow making and servicing activities. Maruhubi receives both domestic and industrial wastes. Sewage wastes from hotels and domestic wastes discharge directly into the Maruhubi coastal area. There is also a transfer point for oil from tankers into receiving facilities at the Mtoni depot near Maruhubi. The Bumbwini Makoba site is in northern Unguja Island. Anthropogenic activities including the combustion of wood fuels, boat/dhow making and repairing of fishing machinery are carried out in the vicinity of the mangrove ecosystem. The Mahonda sugar and alcohol factories are also located close to this area. Within the coastal areas of Mbweni, which lies just south of Zanzibar town, marine transportation and servicing activities occur which use petroleum-based fuels. There are also hotels and residential areas near this site.

Sample collection

Sampling of sediments and crabs was conducted in July and October 2013 at eight sites. For each site, sediment samples were taken at three different points of at least 10 meters apart, starting from near the sea (lower), middle (middle), and furthest from the sea (upper). Surface sediment samples (15 cm deep) were collected from the sampling sites using clean shovels. Crab samples were collected from the selected sampling sites using iron traps. Duplicate crab samples were collected randomly at the same sampling sites. A total of twenty-four sediment samples and twelve crab samples were collected. The samples were

Figure 2. Map showing the location of sampling sites in Unguja Island.

wrapped separately in aluminium foil, transported to the laboratory and stored in a freezer at a temperature below -18 °C until extraction.

Extraction of PAHs

The procedures used by Nasr *et al.* (2010) were adopted for extraction of PAHs in sediments and crabs. Subsamples of sediments (20 g each) were weighed for the determination of dry weights and analysis of PAHs. Each sediment sample was homogenised with 40 g of anhydrous sodium sulphate using a mortar and pestle and added a 250-ml bottle, after which dichloromethane (60 ml) was added and shaken on an ultrasonic bath for 2 h. The extract was decanted and the extraction was repeated twice with 30 ml dichloromethane. The fractions were combined and concentrated in a rotary evaporator at 40 °C up to 2 ml. Cyclohexane (5 ml) was added and concentrated further to 2 ml. Crab soft tissues (20 g) from the body were taken for each sample for the determination of the concentrations of PAHs. Each sample was homogenised by grinding with anhydrous sodium sulphate (40 g), and extracted by shaking with dichloromethane (60 ml) in an ultrasonic bath for 2 h. The extracts were decanted and the sample was shaken again with dichloromethane (30 ml) and left for a night. The combined extracts were concentrated in a rotary evaporator at 40 °C to 1 ml. The solvent was replaced with cyclohexane and concentrated further to 2 ml.

Clean-up of Sample Extracts

Clean-up to remove interferences from extracts was carried out by adsorption column chromatography as per Nasr *et al.* (2010). The adsorbents (silica and alumina) were activated by heating at 130 °C for 12 h and then cooled at room temperature. Alumina was deactivated by adding 5% distilled water. Traces of sulphur in the extracts were removed using activated copper following the procedure described by Gaspare *et al.* (2009). To prepare the activated copper, dilute hydrochloric acid (1.0 M, 20 ml) was added into an Erlenmeyer flask containing copper crystals (20 g). The mixture was shaken for 1 h using an ultrasonicator and then decanted. The decanted activated copper was repeatedly washed with enough distilled water to remove all traces of the acid to avoid degradation of the analytes, and then rinsed with dichloromethane (50 ml) for 1 h. The column was packed with silica gel

(5 g) and alumina (3 g) and rinsed with dichloromethane (5 ml). The extract was added into the column and eluted with a mixture of dichloromethane (20 ml) and cyclohexane (30 ml). For clean-up due to the deposition of sulphur in the sediment extracts, activated copper (1 g) was added to the extract; the mixture was shaken for 10 min and decanted. The extract was concentrated using a rotary evaporator at 40 °C, the solvent replaced with cyclohexane:acetone (9:1), and 1.5 ml of extract was transferred to a vial ready for analysis.

Analysis, Identification and Quantification of PAHs

Gas chromatography-Mass spectrometry (GC-MS) analyses of the cleaned extracts were carried out at the Chemistry Department, University of Dar es Salaam using a Shimadzu GC-MS QP2010 Ultra. The GC processes included: an autosampler, injection volume of 1 µl, injector temperature of 250 °C, pressure of 150 kPa, splitless injection mode with a purge flow of 3 ml/min, helium as carrier gas with flow rate of 2.17 ml/min and average velocity of 54.6 cm/sec, capillary column (Rtx-5MS, 30 m length, 0.25 mm id, and 0.25 µm film thickness), column temperature programme of 90 °C, held for 2 min, then increased at 5 °C/min to 320 °C, held for 12 min and interface temperature of 300 °C. The mass spectrometer processes included: electron impact (EI) ionization, ion source temperature of 230 °C, detector temperature of 300 °C, and full scan mode for the masses between 45 and 500 m/z. The PAHs in the samples were identified by comparing retention times and mass spectra of the analytes against those of standards. Typical retention times and selected masses of the PAHs are shown in Table 2. Quantification of PAHs was performed under known concentrations of the external standards and using peak heights. The mass fragment with the highest intensity was used for quantification (Table 2). Eleven members among the 16 US EPA priority PAHs were analysed.

Analytical Quality Assurance

The samples were wrapped with aluminium foil and kept in clean containers. The chemicals (solvents, reagents and standards) used were of analytical grade and high purity (above 98%). The tools and glassware were cleaned using water and liquid soap followed by rinsing with distilled water and acetone and then the glassware was dried in an oven at 150 °C. Blanks, recovery tests and detection limits were determined. The detection limits were established based on a 3:1 signal to noise ratio. Mixed standards with concentrations of 1-8.33 ppb were spiked into the blank samples (crab and sediment) that were obtained from the Jozani site for recovery tests. The recovery values of PAHs from crabs and sediments (n = 6) ranged between 74.2 and 116.7%, and were deemed acceptable. The detection limits for crabs and sediments ranged from 0.002 to 0.009 ng/g for naphthalene, acenaphthylene, fluorene, anthracene, benzo[a]anthracene, and benzo[k] fluoranthene, and from 0.012 to 0.036 ng/g for benzo[a]pyrene, benzo[b]fluoranthene, indeno[1,2,3-cd] pyrene, benzo[ghi]perylene, and dibenzo[a,h]anthracene. Analytes that gave results below these limits were considered as 'not detected'.

Table 1. A List of PAHs analytes, their retention times and GC-MS masses.

PAHs	Retention time (min)	Quantification mass (m/z)	Qualifying ions (m/z)
Naphthalene	5.89	128	127 – 129
Acenaphthylene	11.77	152	76 – 151
Fluorene	14.83	166	82 – 165
Anthracene	19.06	178	76 – 176
Benzo[a]anthracene	31.14	228	226 –229
Benzo[k]fluoranthene	35.84	252	250 – 253
Benzo[a]pyrene	35.94	252	126 – 253
Benzo[b]fluoranthene	37.06	252	126 – 250
Indeno[1,2,3-cd]pyrene	41.15	276	138 – 277
Dibenzo[a,h]anthracene	41.33	278	139 – 279
Benzo[g,h,i]perylene	41.96	276	138 – 277

Data Analysis

Statistical analyses of the data were performed using Graphpad InStat (Motulsky, 1998). The One-way ANOVA and *t*-test were applied to determine the differences in the concentrations of PAHs in crab and sediment samples. Correlations in the concentrations of PAHs between crabs and sediments were checked using the Pearson's correlation test. All statistical analyses were based on the significance level of $p = 0.05$.

Results and Discussion

PAHs in Crab Samples

PAHs Detection and Concentrations in Crabs

The concentrations of the PAHs in crab samples are shown in Table 2 and the levels and detection frequencies are summarised in Table 3. PAHs were detected in most crab samples with concentrations up to 5.40 ng/g, except for indeno[1,2,3-cd]pyrene, and dibenzo[a,h] anthracene, which were detected in 33.3 and 16.7% of

Table 2. Concentrations of PAHs in crab samples (ng/g fw).

Sampling Site	Wesha		Jozani		Kinazini		Ngezi		Mbweni		Bumbwini Makoba	
PAHs/category	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Naphthalene	ND-3.31	1.66	0.03-0.86	0.45	0.83-3.15	1.99	0.17-2.15	1.16	ND-2.33	1.17	0.62-1.99	1.31
Acenaphthylene	0.13-2.41	1.27	0.05-0.15	0.10	0.15-1.89	1.02	0.15-1.31	0.73	0.17-1.46	0.82	0.19-1.35	0.77
Fluorene	0.35-3.09	1.72	0.06-0.35	0.21	0.32-2.77	1.55	0.41-1.90	1.16	ND-0.56	0.28	0.64-1.67	1.16
Anthracene	0.37-3.12	1.75	0.30-0.55	0.43	0.61-2.96	1.79	0.64-1.73	1.19	0.68-1.98	1.33	0.96-1.74	1.35
Benzo[a]anthracene	1.48-4.32	2.90	0.45-0.60	0.53	0.83-3.42	2.13	1.70-4.56	3.13	0.86-1.96	1.41	0.27-5.40	2.84
Benzo[k]fluoranthene	0.14-2.64	1.39	0.17-0.38	0.28	0.09-1.92	1.01	0.25-1.30	0.78	0.15-1.20	0.68	0.08-1.73	0.91
Benzo[a]pyrene	0.03-2.43	1.23	0.11-0.16	0.14	0.14-1.93	1.04	0.17-1.54	0.86	0.02-1.23	0.63	0.09-1.57	0.83
Benzo[b]fluoranthene	0.47-2.91	1.69	0.20-0.31	0.26	0.30-2.30	1.30	0.53-2.80	1.67	ND-1.30	0.65	0.04-1.79	0.92
Indeno[1,2,3-cd]pyrene	ND	ND	0.33-0.48	0.41	ND-0.73	0.37	ND-1.09	0.55	ND	ND	ND	ND
Dibenzo[a,h]anthracene	ND-2.21	1.11	ND	ND	ND	ND	ND-2.00	1.00	ND	ND	ND	ND
Benzo[g,h,i]perylene	ND-2.22	1.11	ND	ND	ND -0.10	0.05	0.12-1.26	0.69	ND-1.24	0.62	ND-1.57	0.79
Total PAHs (∑PAHs)	2.97-28.66	15.82	1.70-3.85	2.78	4.10-20.33	12.22	5.23-20.54	12.89	2.44-12.70	7.57	2.89-18.80	10.85

Table 3. Minimum, maximum, and mean concentrations of PAHs (ng/g), and the detection frequencies in crabs.

PAHs	Rings	Minimum conc	Maximum conc	Mean ± SD conc	Detection Frequency (%)
Naphthalene	2	ND	3.31	1.29 ± 1.24	83.3
Acenapthylene	3	0.05	2.41	0.78 ± 0.84	100
Fluorene	3	ND	3.09	1.01 ± 1.07	91.7
Anthracene	3	0.30	3.12	1.30 ± 0.99	100
Benzo[a]anthracene	4	0.27	5.40	2.16 ± 1.80	100
Benzo[k]fluoranthene	5	0.08	2.64	0.84 ± 0.89	100
Benzo[a]pyrene	5	0.02	2.43	0.78 ± 0.89	100
Benzo[b]fluoranthene	5	ND	2.91	1.08 ± 1.10	91.7
Indeno[1,2,3-cd]pyrene	6	ND	1.09	0.22 ± 0.37	33.3
Dibenzo[a,h]anthracene	5	ND	2.21	0.35 ± 0.82	16.7
Benzo[g,h,i]perylene	6	ND	2.22	0.54 ± 0.80	50.0
∑PAHs		**1.70**	**28.66**	**10.35 ± 3.44**	100

the samples, respectively, and their concentrations were up to 2.22 ng/g. The highest concentrations of most of the PAHs (nine out of eleven) were recorded in crabs from Wesha. The highest concentrations of benzo[a]anthracene and indeno[1,2,3-cd]pyrene were found in samples from Bumbwini Makoba and Ngezi, respectively. Generally, the concentrations of the PAHs recorded from Jozani crabs were the lowest.

SD = Standard deviation; ND = Not detected

The total concentrations of the PAHs in crab samples varied among the sampling sites. Low molecular weight PAHs were found in samples from most of the sites, while some high molecular weight PAHs like dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene and benzo[g,h,i]perylene were not found in samples from most of the sites. Total PAHs concentrations ranged from 1.70 to 28.66 ng/g. The highest concentrations measured in crabs at Wesha were probably due to oil spills and other anthropogenic activities near the coastal area. The coastal area of Wesha was formerly the site where diesel powered electric generators operated, and currently has an oil depot, which could be the source of contamination of the mangrove ecosystems. Similar results were reported by Ekpo *et al.* (2012) who investigated PAHs contamination and accumulation in the mangrove ecosystem in the Niger Delta. These authors associated PAHs contamination and accumulation in the Niger Delta with petroleum-related activities. Wesha mangrove ecosystem receives contamination of PAHs from both petrogenic and pyrogenic sources. The possible sources of contamination at Wesha station include day-to-day shipping operations and road smelters. Crab samples from Jozani were observed to have the lowest concentrations of PAHs in this study. This is due to low anthropogenic activities in this protected area.

PAHs Profiles in Crabs

The PAHs trend in crab samples showed relatively higher concentrations of low molecular weight PAHs of two to four benzene rings than the high molecular weight PAHs of five to six rings. The dominant compounds were benzo[a]anthracene (four rings) followed by anthracene (three rings) and benzo[b]fluoranthene (five rings). Indeno[1,2,3-cd]pyrene (six rings) showed the lowest concentrations. The findings of low molecular weight PAHs of two to four aromatic rings in crab samples observed in this study could be related to pyrogenic anthropogenic activities, like domestic emissions. Crabs could be exposed to higher concentrations of low molecular weight PAHs than the high molecular weight PAHs because the low molecular weight PAHs are relatively more soluble in the water column compared to the high molecular weight PAHs. Therefore low molecular weight PAHs are more bioavailable despite being less tightly bound to the organic matter in sediments (Eickhoff *et al*., 2003).

Table 4. Concentrations of PAHs in sediment samples (ng/g dry weight).

Sampling site	Wesha		Jozani		Kinazini		Ngezi	
No. sampling points	3		3		3		3	
PAHs/category	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Min	Mean ± SD
Naphthalene	2.99-4.03	3.40 ± 0.55	3.21-3.34	3.26 ± 0.07	3.63-8.30	5.79 ± 2.35	3.51-4.35	3.89 ± 0.43
Acenaphthylene	1.78-2.84	2.26 ± 0.54	2.17-2.38	2.25 ± 0.11	2.30-4.13	3.28 ± 0.92	1.74-3.45	2.34 ± 0.97
Fluorene	2.37-3.41	2.87 ± 0.52	2.79-3.73	3.11 ± 0.54	2.95-6.69	5.04 ± 1.91	2.73-5.40	3.63 ± 1.53
Anthracene	2.35-3.15	2.73 ± 0.40	2.54-3.00	2.82 ± 0.25	5.56-8.04	7.07 ± 1.32	2.12-3.39	2.60 ± 0.69
Benzo[a]anthracene	2.88-3.94	3.31 ± 0.56	ND-2.59	1.68 ± 1.46	8.45-8.68	8.53 ± 0.13	1.92-2.73	2.35 ± 0.41
Benzo[k]fluoranthene	2.10-3.75	2.74 ± 0.88	1.93-2.38	2.19 ± 0.23	8.93-9.51	9.15 ± 0.31	1.64-2.14	1.97 ± 0.29
Benzo[a]pyrene	1.89-2.87	2.39 ± 0.49	2.02-2.24	2.11 ± 0.12	6.54-7.12	6.83 ± 0.29	1.57-7.65	3.75 ± 3.39
Benzo[b]fluoranthene	2.35-3.33	2.74 ± 0.52	1.99-2.10	2.04 ± 0.06	8.40-8.93	8.63 ± 0.27	1.63-2.10	1.90 ± 0.24
Indeno[1,2,3-cd]pyrene	2.81-3.55	3.28 ± 0.41	2.14-2.19	2.16 ± 0.03	10.40-11.90	11.28 ± 0.78	1.70-2.47	2.06 ± 0.39
Dibenzo[a,h]anthracene	1.88-2.93	2.38 ± 0.53	1.96-2.04	2.00 ± 0.04	3.05-3.96	3.53 ± 0.46	ND-1.75	0.58 ± 1.01
Benzo[g,h,i]perylene	ND-2.38	1.43 ± 1.26	ND-2.14	1.42 ± 1.23	6.58-8.06	7.56 ± 0.85	ND-1.98	1.19 ± 1.05
∑PAHs	26.20-33.78	29.52 ± 3.88	21.95-26.87	25.04 ± 2.70	67.02-81.94	76.70 ± 8.40	20.14-31.78	26.26 ± 5.84

The total PAHs levels from edible crab tissues obtained in this study were much lower than the levels reported by other authors for crabs in highly contaminated areas. For instance, Mostafa (2002) found concentrations ranging from 1318.6 to 3767.4 ng/g for total PAHs in crabs from Lake Timsah, while Ekpo *et al.* (2012) reported mean total PAHs levels of 29325.1 ng/g ww in crabs from the Calabar River, Niger delta. The mangrove ecosystems of Zanzibar coastal areas are less impacted by anthropogenic activities compared with those areas studied by Mostafa (2002) and Ekpo *et al.* (2012).

PAHs in Sediment Samples

PAHs Detection and Concentrations in Sediments

The PAHs concentrations in the sediment samples are shown in Table 4 and the levels and detection frequencies in sediments are summarised in Table 5. Total PAHs concentrations in sediments ranged from 20.14 to 81.94 ng/g dw. PAHs were detected in most sediment samples with concentrations for individual compounds up to 11.90 ng/g. The highest concentrations of most PAHs in sediment samples were detected at Kinazini. Kinazini is a commercial area from which there is direct release of domestic wastes and municipal wastewater to the mangrove ecosystem. Boat making and servicing and oil spills from service stations and other products of anthropogenic activities could be contributing to the contamination in this area. Kinazini receives contamination from domestic sewage from the urban area especially through the stream which passes through the area. Ngezi is a government preserved area and there are low anthropogenic activities within this area. However, the area receives contamination from nearby areas probably due to forest fire and agricultural burning, which contribute to the levels of PAHs found. PAHs are also known to be synthesised by some higher plants, microorganisms and some animals (Eisler, 1987; Mohanraj & Azeez, 2003).

The concentrations of the PAHs detected in sediments during this study are comparable to the results obtained for PAHs levels from the Niger Delta which ranged from 0.1 to 28 ng/g (Anyakora *et al*., 2005).

PAHs Profiles in Sediments

The results suggest that both petrogenic and pyrogenic sources contributed to the contamination of the sediments in the study areas since both high and low molecular weight PAHs were found in the sediment samples. The nature of contamination sources controls the molecular distribution of the PAHs, although there are other factors like photo-oxidation, biodegradation, evaporation and dissolution that lead to degradation of specific compounds that also affect the pollutants distribution (Neff, 1979). Generally, the low molecular weight PAHs were found to be in low percentage concentrations in sediment samples

Table 4 (Ctd). Concentrations of PAHs in sediment samples (ng/g dry weight).

Sampling site		**Mbweni**		**Maruhubi**	**B. Makoba**		**Donge Muwanda**
No. sampling points		**3**		**3**	**2**		**3**
PAHs/category	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Mean**	**Range**	**Mean ± SD**
Naphthalene	2.32-3.49	2.89 ± 0.59	2.42-3.21	2.92 ± 0.43	2.66	3.31-5.32	4.02 ± 1.13
Acenaphthylene	1.60-2.52	2.09 ± 0.46	1.69-2.26	2.01 ± 0.29	1.74	1.53-2.68	2.14 ± 0.58
Fluorene	2.59-3.12	2.94 ± 0.31	3.14-4.82	3.90 ± 0.85	2.81	2.17-3.95	2.97 ± 0.90
Anthracene	2.05-3.02	2.68 ± 0.54	2.63-4.33	3.26 ± 0.93	2.40	2.18-4.99	3.37 ± 1.46
Benzo[a]anthracene	2.42-2.57	2.52 ± 0.08	2.65-2.92	2.77 ± 0.14	2.34	2.58-4.73	3.67 ± 1.08
Benzo[k]fluoranthene	1.69-2.54	2.15 ± 0.43	2.20-2.58	2.39 ± 0.19	1.81	2.52-3.66	3.17 ± 0.59
Benzo[a]pyrene	1.63-2.20	1.99 ± 0.32	2.10-2.29	2.18 ± 0.10	1.69	2.25-3.03	2.66 ± 0.39
Benzo[b]fluoranthene	1.77-2.21	2.05 ± 0.24	2.26-2.52	2.35 ± 0.14	1.87	2.31-3.86	3.04 ± 0.78
Indeno[1,2,3-cd]pyrene	2.16-2.23	2.20 ± 0.04	2.41-2.79	2.54 ± 0.21	2.22	2.43-3.86	3.24 ± 0.73
Dibenzo[a,h]anthracene	1.48-1.98	1.80 ± 0.28	1.75-1.99	1.83 ± 0.14	1.50	1.29-2.35	1.88 ± 0.54
Benzo[g,h,i]perylene	1.55-2.10	1.91 ± 0.31	1.82-2.13	1.99 ± 0.16	1.51	2.00-2.68	2.44 ± 0.38
∑PAHs	21.32-27.17	25.22 ± 3.38	26.72-30.77	28.17 ± 2.26	22.54	27.45-38.39	32.59 ± 5.50

Table 5. Minimum, maximum, and mean concentrations of PAHs (ng/g), and the detection frequencies (%) in sediments samples.

PAH	Minimum conc	Maximum conc	Mean ± SD	Detection Frequency (%)
Naphthalene	2.32	8.30	3.69 ± 1.29	100
Acenaphthylene	1.53	4.13	2.31 ± 0.66	100
Fluorene	2.17	6.69	3.46 ± 1.15	100
Anthracene	2.05	8.04	3.45 ± 1.67	100
Benzo[a]anthracene	ND	8.68	3.49 ± 2.22	95.5
Benzo[k]fluoranthene	1.64	9.51	3.32 ± 2.44	100
Benzo[a]pyrene	1.57	7.65	3.07 ± 1.96	100
Benzo[b]fluoranthene	1.63	8.93	3.19 ± 2.27	100
Indeno[1,2,3-cd]pyrene	1.70	11.90	3.75 ± 3.12	100
Dibenzo[a,h]anthracene	ND	3.96	1.98 ± 0.92	90.9
Benzo[ghi]perylene	ND	8.06	2.52 ± 2.21	86.4
∑PAHs	**20.14**	**81.94**	**34.23± 6.45**	100

while the high molecular weight PAHs were found to be in high percentages. Some low and high molecular weight PAHs showed similar dominance in sediment samples. This is due to the relatively higher hydrophobic and lipophilic characteristics of high molecular weight PAHs, which make them less soluble in water and likely to settle to the bottom of the aquatic environment and bind tightly to the organic matter in sediments (Sakari, 2012). The concentrations of PAHs in sediments observed from this study were due to the hydrophobicity of the PAHs which allows them to easily adsorb to the sediments (Deschenes *et al*., 1996; Karthikeyan & Bhandari, 2001).

Comparison of PAHs Concentrations in Crabs and Sediments

The results showed that there was no significant correlation between the concentrations of total PAHs in crabs and sediments (r = 0.2103, df = 22, p = 0.5347). This indicated that the crabs are exposed to PAHs from various sources such as water. Generally, the samples collected near to the mangrove ecosystem (upper samples) had the highest concentrations of PAHs (mean = 3.50 ng/g), followed by middle samples (mean = 3.30 ng/g), and the lower samples collected nearest to the sea-line had the lowest concentrations (mean = 2.74 ng/g). This is due to the characteristics of the mangroves to trap organic materials from the water column where the PAHs can bind tightly (Sanders *et al.*, 2010). However, the results from ANOVA showed that there were no significant differences in the PAHs concentrations in sediments among the upper, middle and lower sections of the sampling locations for most sites (F (2,30) = 0.9491 – 2.542, p = 0.0955 – 0.398), which suggested even distribution of the contaminants. There were significant differences in the PAHs concentrations in sediments among the upper, middle and lower sections of the sampling locations at Mbweni (lower < middle and upper; F (2, 30) = 5.563, p = 0.0088) and Donge Muwanda (lower < middle and upper; F (2, 30) = 3.689, p = 0.037). This could be attributed to the differences in sediment composition among the locations of the mangrove stands, leading to differences in trapping of PAHs. The concentrations of the PAHs in sediments were significantly greater than the concentrations in crabs (t = 4.279 at df = 32, p = 0.002). This is due to the fact that sediments act as reservoirs or sinks, and therefore tend to accumulate more contaminants.

Evaluation of PAHs Contamination in Mangrove Ecosystems in Zanzibar

The data from the present study were compared with the data reported in the literature for the maximum permitted levels of PAHs in crabs for food safety (European Commission, 2011). The maximum permitted level for benzo[a]pyrene is 2 ng/g ww while the cumulative permitted level for benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene and chrysene is 12 ng/g ww (European Commission, 2011). The crabs from Wesha were found to contain benzo[a]pyrene concentrations above the maximum permitted level

making them potentially harmful for consumption by human beings. The concentrations of individual PAHs in sediments from the coastal areas of Zanzibar did not exceed the Threshold Effect Level (TEL) and were below the Probable Effect Level (PEL). PEL is the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects, and TEL is the upper limit of the range of sediment contaminant concentrations that is associated with no effect. The TEL for naphthalene is 34.6 ng/g, other TELs are 5.87 ng/g for acenaphthylene, 113 ng/g for fluorene, 46.9 ng/g for anthracene, 74.8 ng/g for benzo[a]anthracene, 88.8 ng/g for benzo[a]pyrene, 6.22 ng/g for dibenzo[a,h]anthracene, and 108 ng/g for chrysene. The PEL for these compounds range from 128 to 1494 ng/g (MacDonald, 1994).

Conclusions

All the crab and sediment samples from the mangrove ecosystems in the Zanzibar Islands coastal areas were found to be contaminated with various types of PAHs, which could be related to pyrogenic and petrogenic sources, among others. The total concentrations of PAHs in crab tissues were up to 28.66 ng/g fw, while the highest concentration of total PAHs in sediment samples was 81.94 ng/g dw. The levels of the PAHs in crabs were lower than the PAHs levels in sediments. In sites with high anthropogenic activities like Kinazini, the level of contamination in sediments was higher than in areas with low anthropogenic activities. The levels of contamination were generally low, except in crabs from one site (Wesha).

Acknowledgements

This study was supported by the Tanzania Commission for Science and Technology (COSTECH).

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Status of the mud crab fishery in Kenya: A review

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Abstract

Most indigenous coastal populations (70%) have a high dependency on, and preference for, marine fisheries. However, most fishers are financially handicapped and thus do not invest in the fisheries that require relatively high financial capital (to purchase fishing gears and vessels). A higher proportion of fishers depend on near shore fisheries that are easily accessed by foot or dugout canoes. In Kenya, mud crabs are fished mainly by men and to a lesser extent by women and children due to the accessibility of the fishing areas by foot. This makes mud crabs a key fishery that is easily accessible for exploitation by most coastal artisanal fishers for subsistence and commercial purposes. Mud crabs have been a delicacy in the local tourist hotels for a number of years. In addition, the previously minimal export market for mud crabs from Kenya has increased drastically over the last two decades. The requirement for wild mud crab seed in aquaculture has also increased over the last decade. The demand for all sizes of mud crab to meet the requirements of the different market chains in Kenya require effective management approaches to guide exploitation of the fishery. The development of Beach Management Units (BMUs) as outlined in the National Oceans and Fisheries Policy of 2008 and the Fisheries Management and Development Act of 2016, if well implemented, enhance management of the fishery. Further, adoption of the new Constitution (2010) and establishment of county and national governments calls for harmonization of roles to address localised management issues such as for the mud crab fishery, that is currently declining in small mangrove creeks.

Keywords: Mud crabs, exploitation, artisanal fishers, export, aquaculture, management

Introduction

Mud crab (*Scylla serrata)* is a decapod crustacean that spends most of its life in the mangrove environment throughout its range. It has high meat quality and nutritional value hence its fishery forms a significant economic activity in coastal areas in the tropics and sub-tropics. They form an important source of food and income for most local communities (Keenan *et al*., 1998; Keenan, 1999; Le Vay, 2001; Bonine *et al*., 2008). A number of communities along the East African coast are involved in mud crab fisheries although, due to the nature of the fishery, it is difficult to collect reliable data which can provide information on catch rates and trends (Barnes *et al*., 2002; Richmond *et al*., 2006; Mirera, 2011).

Globally, artisanal mud crab (*Scylla spp.*) fishers use several methods for capturing the crabs, which have changed over time (Bonine *et al*., 2008). The methods for capture are generally similar throughout the tropics but the techniques may differ somewhat from one region to another depending on habitat complexity and traditions of fishers (Perrine, 1978; Le Vay *et al*., 2001; Ochiewo, 2006; Bonine *et al*., 2008). The dominant capture methods include: baited crab pots; baited traps; hooked wooden/metal rods; baited lines attached to a pole; scoop nets; head lights/torches with scoop nets; gill/seine nets; intertidal collection by hand; and baited lift nets (Hill *et al*., 1982; Overton *et al*., 1997; Le Vay *et al*., 2001; Barnes *et al*., 2002; Walton *et al*., 2006; Lebata *et al*., 2007; Bonine *et al*., 2008; Mirera *et al*., 2013).

In Kenya and East Africa in general, burrow fishing is a common technique of collecting market size (above 0.5kg) crabs for sale, and sub-adult (0.1-0.5 kg) crabs for cage and pen culture (Muthiga, 1986; Barnes

et al., 2002; ACDI/VOCA, 2005; Mahika *et al*., 2005; Richmond *et al*., 2006; Fondo, 2006; Fondo *et al*., 2010; Mirera, 2009, 2011). This fishing technique requires considerable experience to manage, otherwise, crabs are damaged thus reducing their market value (Mirera and Mtile, 2009; Nirmale *et al*., 2012). Fishers frequently check burrows inside their respective fishing territories and collect individuals found on, or buried in, the sediment (Mirera *et al*., 2013).

Population studies of mud crabs in Kenya have previously indicated a fishery that was previously only lightly exploited with potential for improved income generation if sustainably managed (Muthiga, 1986; Mirera, 2011, 2012; Fondo *et al*., 2010). However, site- or region-specific declines in catches have been observed in some assessments in Kenya and East Africa (Mahika *et al*., 2005; Fondo, 2006; Richmond *et al*., 2006). Based on the capture details from artisanal fishers in Kenya, there has been a drastic decline in the number of market size (0.5 kg) crabs being collected from small creeks over time, and this has affected exporters of the product, forcing them to diversify to other products (Mirera *et al*., 2013; Roy Aseka, pers com; Fig. 1). The mud crab fishery occurs throughout the year with small seasonal variations in quantities of landings (Muthiga, 1986; Onyango, 2002; Mirera *et al*., 2013). Recruitment into the fishery also occurs throughout the year with no specific peaks (Mirera, 2014).

Objectives and scope of the review

The main objective of this review is to assess the level of exploitation of the mud crab fishery in Kenya, its potential to meet the livelihood demands of coastal communities, and management interventions that could ensure sustainable utilization. The assessment has been based on the available literature on mud crab fishery production, exploitation methods and management interventions. The review also considered available databases on mud crab production, stock assessment and other related studies such as tagging experiments. To understand the management approaches, policies and other legal documents related to fisheries management, including the constitution of Kenya 2010, were considered. The different aspects of the fishery have been compared to studies on similar fisheries elsewhere in the world. To conclude, we identify knowledge gaps related to the development and exploitation of the fishery, and management interventions needed to ensure sustainability.

Mud crab diversity

More than four decades ago, the genus *Scylla*, was considered monotypic globally, irrespective of clear

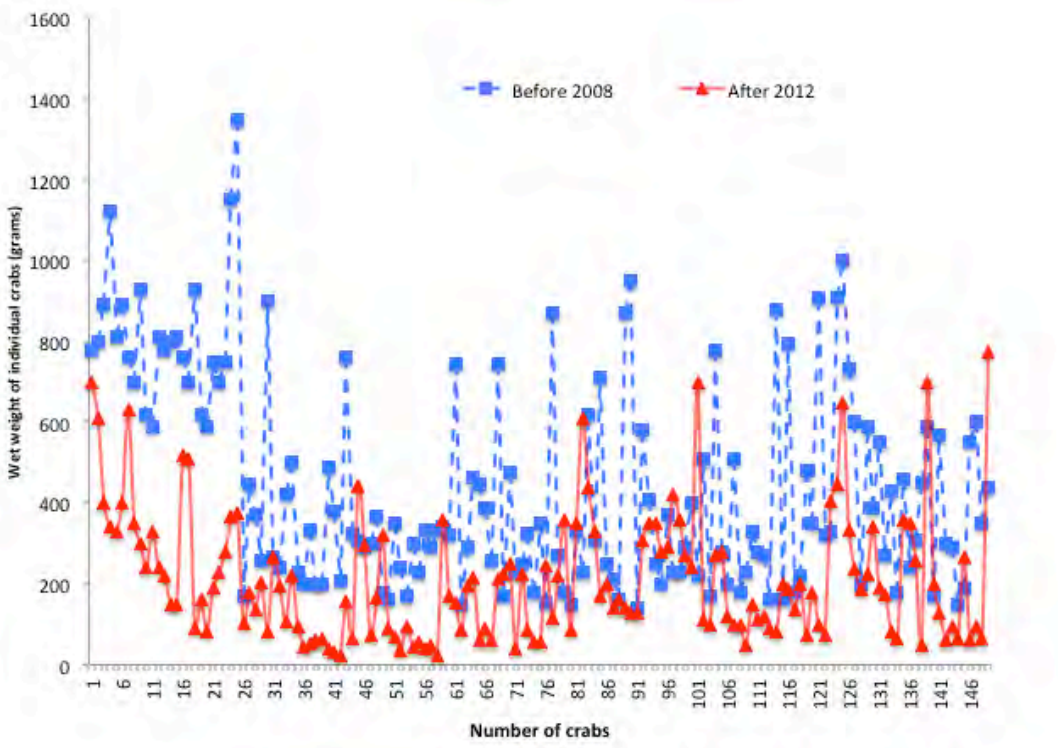

Figure 1. Comparative assessment of the size frequency of mud crabs caught by fishers at Mtwapa creek before 2008 and after 2012 (Data source: Kwetu Training Centre records, IFS and WIOMSA tagging experiments).

morphometric differences (Serene, 1952; Ong, 1964). However, it was revised in the last decade and a total of four species were identified (Keenan *et al*., 1998). The four species of mud crabs now globally accepted are *Scylla serrata*, *S. paramamosain*, *S. tranquebarica* and *S. olivacea*. Of the four species, only one (*S. serrata*) has been identified in Kenya (Fratini and Vannini, 2002) through samples taken from Mida creek, Gazi Bay and Lamu. However, only few genetic studies have been done in this area to provide clear indications on the exact number of mud crab species along the Kenya coast. Using the morphometric differences, there are indications of a second species in Kenya, suggesting that more research on mud crab systematics is required (Mirera, 2011). Based on the demand for mud crab in mariculture development (Mirera, 2011; Moksnes *et al*., 2015), adequate research is required on species diversity to enable informed management decisions on stocks, habitat change, mariculture technology development, and hatchery establishment.

Mud crabs and the mangrove environment

Mangrove tree formations contribute to the marine food web through their production of detritus and commercially important species of marine animals (crabs, fish and shrimps) are known to spend at least part of their life cycle there (Nagelkerken *et al*., 2008; Mirera *et al*., 2010). Indeed, for decades adult/market size mud crabs (*S. serrata*) in Kenya have been harvested from holes in mangrove swamps during the day at low spring tides by expert fishers (Fondo, 2006; Mirera, 2011; Mirera *et al*., 2013). Crab populations are typically associated with mangroves globally and are at times used as indicators for mangrove habitat condition (Hill *et al*., 1982; Walton *et al*., 2006). They are abundant in estuaries and mangrove swamps at some stage in their life cycle (Muthiga, 1986; Overton *et al*., 1997; Onyango, 2002; Walton *et al*., 2006). Mangrove habitat utilisation begins when crabs settle out from the plankton developmental stage of instar 1, and may continue to the adult stage when they move out for spawning in deep waters (Walton *et al*., 2006; Mirera, 2014).

Juvenile mud crabs are common in intertidal mangrove habitats, on mudflats or in mangroves stands (Hill *et al*., 1982; Mirera, in press) while larger crabs are found in mangrove channels, near the shore or in burrows. During low tides, individual crabs are found in burrows on the mud within the mangrove roots or basal mangrove tree holes (Nandi and Dev Roy, 1991; Barnes *et al*., 2002; Fondo, 2006; Mirera *et al*., 2013). The burrows have also been observed to harbour crabs that are almost at the stage of moulting. Burrow occupancy has been used to study crab abundance and utilization of the mangrove forest and is rated at 5-10% based on the area and region (Barnes *et al*., 2002; Fondo, 2006).

Harvesting strategies and methods

Artisanal fishers engage in mud crab fishing in Kenya both during the day and night. Most of the catch is not landed at gazetted landing sites as stipulated in the Fisheries Management and Development Act of 2016. In most cases the fishery is operated without the use of vessels by fishers on foot moving within the mangrove forest covering large areas in a day with no specific landing areas. Most of these fishers operate without a fishing license and therefore do not declare their catch at designated landing sites due to fear of being caught for contravening the law. This is coupled with the fact that most of the small and micro-landing sites are not gazetted and are inaccessible (National Oceans and Fisheries Policy, 2008), suggesting that only localized management strategies like Beach Management Units (BMUs) would be effective in managing the fishery.

Mud crab fishers are known to accumulate harvests at home before sale, thus making catch records at landing sites unattainable and misleading (Mirera *et al*., 2013). Lack of appropriate records and management protocols for the fishery, despite the well-stipulated regulations in the National Oceans and Fisheries Policy 2008 and the Fisheries Management and Development Act 2016, could be responsible for the apparent low current catch levels. Previous studies have shown that harvested crabs in Kenya are consumed at family level, sold to private homes or tourist hotels, or exported (Muthiga, 1986; Mirera, 2011; Moksnes *et al*., 2015). The implication is that harvest records in Kenya and East Africa in general are based on information from mud crab intermediaries, or buyers, but not at the fish landing sites as required by law (Fisheries Management and Development Act, 2016). Thus there is a likelihood of under estimation of catches of up to 40% (Mirera *et al*., 2013). The accumulation of mud crabs over a number of days before being taken to the market also leads to loss of individual weight and mortality, and reduced value of the fishery. This has inflicted large losses to mud crab exporters who depend on fishers to supply them with live mud crabs for sale.

As a result of the harvesting characteristics of the fishery, it becomes complicated to determine an accurate

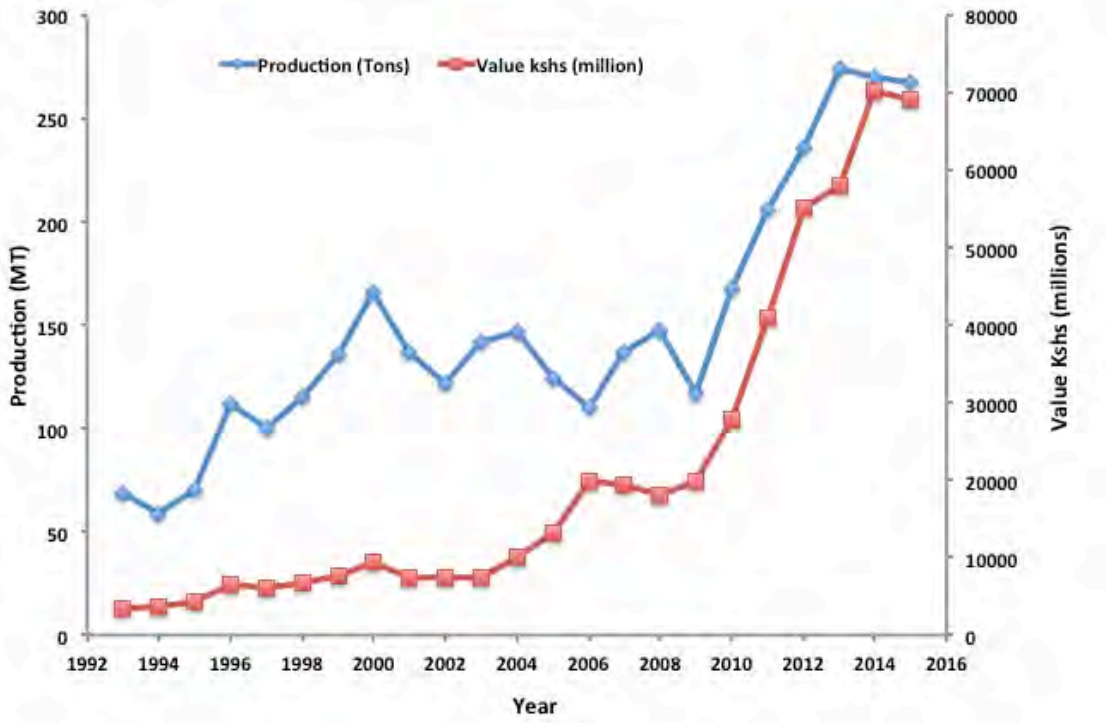

Figure 2. Mud crab (*Scylla serrata*) fishery production (MT) trends and catch value (Ksh) along the coast of Kenya for the period 1990 to 2015 (Data source: Fisheries annual statistics database 1993-2013, and Fisheries catch statistics data for 2014-2015): 1USD = 102Kshs.

CPUE for mud crabs, with most studies relying on information from market intermediaries, or hole counts and interviews with crab fishers (Horrill *et al*., 1996; Barnes *et al*., 2002; Fondo, 2006; Ochiewo, 2006; Richmond *et al*., 2006).

The choice of a fishing area and method for mud crab fishers depends on the target crabs being fished and the skill and equipment required. More than 60 % of the fishers fish for adult mud crabs in burrows within the mangrove swamps at low tide using traditional hooks and sticks. Other fishers use baited traps, scoop nets or seine nets along the seaward mangrove fringe and channels. Almost all crab fishers practice fishing by foot with limited use of equipment, but with a wide local knowledge of the fishing area (Jones *et al*., 2008; Ochiewo *et al*., 2010). Fishing is never random, it follows specific patterns, mainly depending on the knowledge of the fisher of preferred mud crab areas where the harvest is likely to be high, or on visiting hereditary burrows (Dumas *et al*., 2012; Mirera *et al*., 2013).

Crab fishing in Kenya mainly occurs during the early morning rather than later in the day or in the evening. Fishing is mainly influenced by tidal regimes irrespective of the fishing technique applied (Moser *et al*., 2005; Mirera *et al*., 2013). Fishers prefer to fish during low spring tides and return at high spring tides with only limited fishing taking place during neap tides (locally known as *maji mafu*). Mud crabs found in burrows at neap tide are usually in the moulting period, or have just moulted, and have no market value in Kenya, despite the recently developed market for such crabs in Asia (soft shell crabs). Moulted crabs collected at neap tides are mainly consumed at the family level.

Recent trends in mud crab capture fishery and markets

Mud crab fisheries production has increased over the years from 90 MT in 1990 to more than 250 MT from the year 2013. Despite small annual variations, there has been a constant increase in mud crab landings with small drops seen in 2001-2003 and 2006-2008 respectively (Fig. 2). The value of the catch has constantly increased possibly as a result of diversification in market outlets for the product. Increased demand from the local tourism industry and export markets has resulted in an observed increase in mud crab fishing effort, and capture of small sized crabs in Kenya and East Africa (Barnes *et al*., 2002; Mirera, 2011; Mirera *et al*., 2013). Larger volumes of mud crab production observed after 2008 could be associated with the demand in the export market (Ochiewo, 2006; Mirera, 2011, 2014).

Currently the mud crab catch-per-unit-effort (CPUE) has been estimated at 0.25-1.7 kg/hr/fisher and each fisher can spend between 2.5-5.0 hr/day fishing (Mirera *et al*., 2013). The individual weight of crabs caught currently range between 0.25 and 0.9kg, which is a significant decline from the 0.5-1.5kg per crab caught 2-3 decades ago (Muthiga, 1986; Onyango, 2002). The capture of crabs of more than 0.5kg individual weight has declined over the last four years in small creeks (Roy Aseka, per com; Fig. 1). Mud crab fishing by foot fishers is mainly influenced by spring tides, however time spent and frequency of fishing may also be affected by market demand. According to Barnes *et al*., (2002), fishers will move for long distances to look for crabs depending on the market demand and need for food at the family level, implying that fishing skills, and the ability to move faster and further in the mangrove forests, could contribute to good catches. In addition, a crab fisher could either make two fishing trips/week as in the case of Chole Island in Mafia, Tanzania (Barnes *et al*., 2002) or fish daily during spring tides as in Kenya (Mirera, 2014; Mirera *et al*., 2013) so as to meet the market demand and family needs.

In Kenya, Lamu County is ranked the highest producer of mud crabs at 48.2%, followed by Kwale (26.4%), Mombasa (11.2%), Kilifi (11.9%) and Tana River (2.3%) (Government of Kenya, 2014). The main mud crab areas include Vanga, Shimoni, Majoreni, Ngomeni, Gongoni, Kurawa, Mkokoni, Kiunga and a number of the many Lamu Islands (Muthiga, 1986; Government of Kenya, 2014; Fig. 3). Most of the areas producing mud crabs occur in three counties (i.e. Lamu, Kwale and Kilifi). The lower percentage contribution of mud crab by Kilifi County could be associated with the fact that most crabs are consumed at local tourist hotels in Malindi and Watamu, and are thus not reflected in the catch data. The high contribution of mud crab landings from Mombasa, which has only small mangrove creeks compared to the other areas, could be as a result of more efficient monitoring of landings due to its proximity to the headquarters of the regulating agency, or due to the double entry of catches from other counties that have been brought to the market in Mombasa as a main coastal hub. Generally, there has been an increased demand for mud crabs both for the domestic and the export market leading to a drastic decline in the size of mud crabs captured in creeks such as Mtwapa, Kilifi, Tudor, and Mida over time (Fig. 1; pers obs). Even though the number of the juvenile crabs is high in the same creeks, there are indications that recruitment into the fishery is declining as a result of fishing pressure (Mirera, 2017).

Socio-economic Characteristics

Fishing for mud crabs is an important livelihood activity for many households along the coast of Kenya. It has been ranked as a key artisanal commercial fishery that requires stock assessment for improved management (KCDP, 2013). Mud crab fishers in Kenya account for 2.9 - 3.5% of the total number of fishers (12,915 fishers) in marine waters (Government of Kenya, 2014). However, the precise number of fishers in this fishery is difficult to establish since most of them do not acquire a fishing license. The average household size of crab fishers in Kenya is about 6.8 persons and similar to what has been recorded for other artisanal fisheries (Ochiewo *et al*., 2010; Mirera, *et al*., 2013). This implies that conservatively, the fishery directly supports more than 2,600 people, and more than 20,000 people indirectly through different supply chains and linked activities such as hotels, restaurants, transport, export, education, eco-tourism and research, among others.

The crab fishery has a limited number of entrants due to the extensive skills required and the harsh mangrove environment where it's practiced. As a result, over the years men aged between 23 and 55 years have dominated the fishery. The scenario is different in the artisanal finfish industry where age composition of fishers ranges between 15 and 45 years (Fulanda *et al*., 2009). Further, crab fishing skills are passed on from one generation to another (heredity), and in some cases from close friends through peer learning. This naturally limits exploitation of the fishery. Such limitations constitute a self-regulating mechanism for the fishery (Mirera *et al*., 2013). Self-regulation can be positive because with relatively limited effort and awareness it is possible to manage the fishery effectively, since participants are conversant with each other at a local level, and local management interventions could succeed if well administered. However, it may be negative since most of the fishers are related to each other making disclosure of non-compliance difficult. Involvement of mud crab fishers in BMU hierarchies may help address issues of compliance to regulations in the fishery.

According to government statistics, the value of landed mud crabs has continually increased from 1993 to 2015 (Fig. 2). In 2015, the fishery was valued at about 70 million Kshs (70,000USD), contributing between 3.5 – 5.5 % of the total value of Kenya's marine fisheries (Government of Kenya, 2014; KCDP, 2015). Such an increase in value may encourage entry into the fishery or increase the frequency of fishing, thus increasing fishing effort

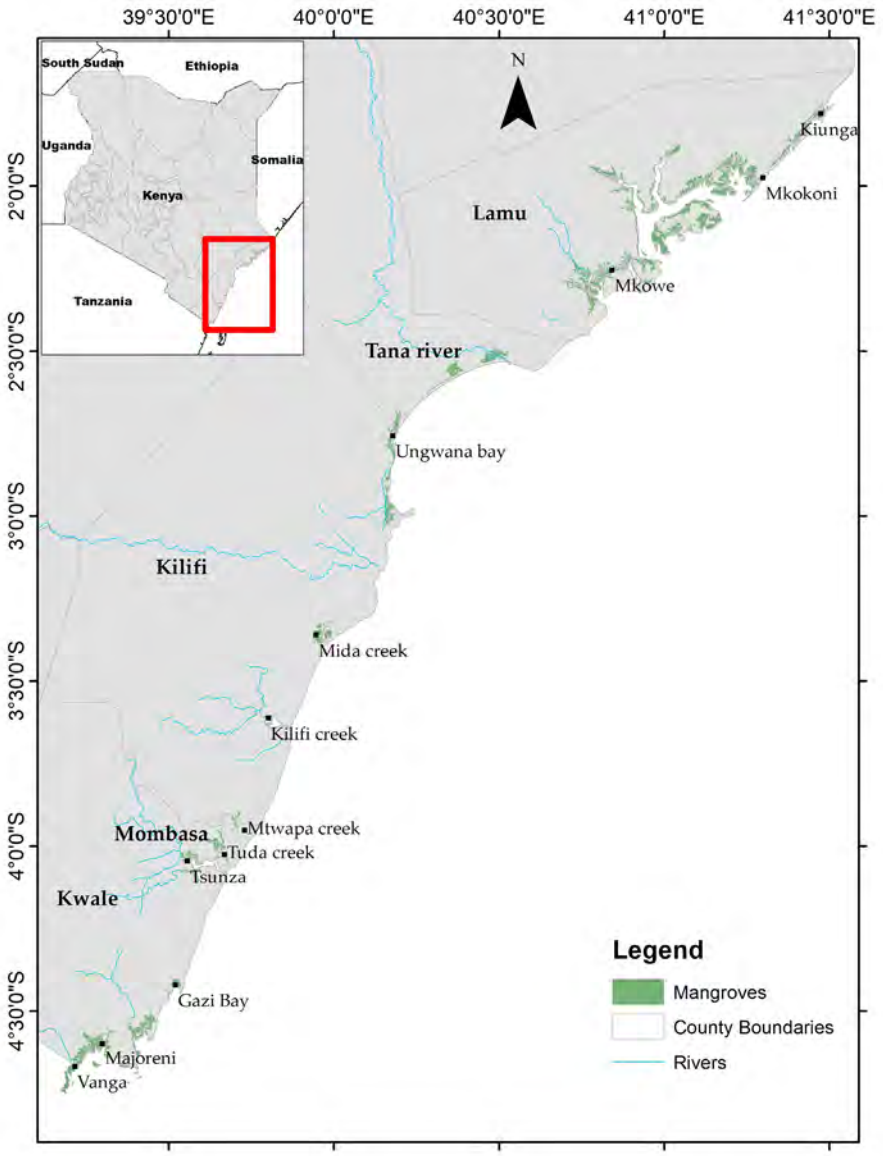

Figure 3. Map of the Kenya coast showing the different counties and mangrove areas where mud crab fishing is practiced.

that may have negative impacts on available stocks. The crab fishery in Kenya has a complex market chain that involves middlemen at different stages, resulting in relatively low profitability for ordinary fishers (Mirera *et al*., 2013). The crab price on the open market varies from 0.2-0.5 USD/kg when sold to locals for home consumption, to 2-5 USD/kg when sold to private homes and in tourist hotels, and 8-15USD/kg when sold for export (Mirera *et al*., 2013). Such price variations are mainly associated with differences in the size of crabs sold and the nature of the market.

To popularize the eating of crab, local tourist hotels have innovatively developed special crab eating techniques, which include a small traditional club for shell breaking, a bib, a small hand towel, and a traditional pot with warm water for occasional hand cleaning (Mirera *et al*., 2013). A good example of the cultural value of mud crabs comes from the island of Kosrae in the Federated States of Micronesia, where adult mud crabs make up a central part in family feasts and are used as gifts to visitors. This has ensured that residents/fishers receive good prices for their crabs (Bonine *et al*., 2008).

Recently, a local community in Kenya has introduced an innovative value addition technique to improve the value of the product sold in their own eco-restaurant located in the mangrove forest on Mida Creek. Crab meat is used to make samosas that are sold at the restaurant by the Dabaso Conservation Group. They are able to make 4 crab samosas from one crab weighing

0.5-0.8 kg. Each of the samosas are sold for 200Ksh (2USD) thus increasing the value one crab to 800Ksh (8USD) (Misinga, pers com). This is four times more than a kilo of fresh mud crab sold in the local market by fishers. This suggests that even without the export market where prices are high, innovative value addition of crabs in the local markets can create employment and enhance income to the local communities through direct marketing to the public. Further, it is noted that mud crabs are mainly served in coastal hotels and there is potential to expand the market to inland hotels in major towns such as Nairobi, Nakuru, Eldoret and Kisumu, among others. Exploitation of such potential will improve the value of the fishery and bring profitability to the fishers.

Emerging Issues

In the last two decades there has been much interest in mud crab farming in Kenya. However, there are no hatcheries to provide seed for the industry (Mwaluma, 2002, 2003; Mirera, 2009, 2011). All the crabs used in fattening (adult lean crabs) and grow out (juvenile and sub adult) are collected from the wild (Mirera and Moksnes, 2015). Recent studies have shown that collection of juvenile crabs occurs in the intertidal boundary zones and are accessible to a wide range of collectors, including women and children who usually do not penetrate deep into the mangrove forests to catch bigger crabs (Mirera *et al*., 2013). The development of mud crab aquaculture targeting all stages of mud crab creates a new challenge to management of the fishery. The ability to collect juveniles easily compared to adults creates a risk of over-exploitation from aquaculture if no management interventions are put in place (Mirera, 2011).

Further, there is an increased mud crab export market in Kenya, mainly to Singapore, Dubai and China. This has encouraged the exploitation of undersized (less than 0.5kg) crabs in an effort to meet the market demand. High mortalities in the transportation and export process lead to wastage of the harvested resource. The current export value chain provides the importer with the authority to decide on what percentage of shipped mud crab is declared fit for their market. Local exporters have no agents in the importing destinations to confirm the state of shipped crabs, and therefore relies on importers to provide information on the state of crabs upon arrival. This could allow for the exploitation of exporters and a consequent loss of value to the fishery, with negative implications for the livelihoods of fishers and the economy.

This underscores the need to re-organize the mud crab fishery in all respects, including monitoring compliance with minimum size limits, ensuring fishers are licensed, recording landings properly, improving collection and storage of the crabs before marketing, and instituting a reliable system to monitor shipments in importing countries.

Legal Framework and Management Status

In the last five years, a co-management approach was adopted in Kenya to support the management of fisheries resources through the establishment of BMUs. According to the Fisheries Management and Development Act 2016, a BMU is defined as an organization of fishers, fish traders, boat owners, fish processors and other beach stakeholders who traditionally depend on fisheries activities for their livelihoods. The BMU was established to ensure structured community participation in fisheries management through supporting conservation, management and development of their local areas. This involves participation in the Interagency Monitoring Control and Surveillance Unit that is established by the Permanent Secretary in the relevant Ministry. BMUs have the right to manage a specific co-management area, impose levies and charges in these areas, manage the proceeds of these, and have a responsibility to protect marginalized groups such as youth and women working in their areas of jurisdiction.

Despite the fact that BMUs are working well, their mandates have not been fully achieved due to limited capacity (resources and personnel) to create awareness and provide monitoring and surveillance for the various fisheries resources, including mud crabs. They lack capacity to track down artisanal mud crab fishers as they do not land or operate at designated landing sites (Mirera *et al*., 2013). To reach mud crab fishers requires extra resources, time and incentives for patrols, to create awareness on the need for landing in designated sites, and to obtain the required operational license. It is therefore necessary to ensure active involvement of experienced/knowledgeable artisanal mud crab fishers in top BMU management structures to facilitate support for the process, and help to unlock the potential of the fishery through knowledge and information sharing (Steel *et al*., 2005; Laurens, 2012).

The Forest Conservation and Management Act of 2016 provides an avenue for co-management of forests in Kenya. The Act allows for the creation of forest user groups (communities who want to use forest areas for

their livelihoods) and recognizes forest communities (communities who have a traditional association with forests either through livelihoods, religion or culture). These are operationalized through the establishment of Community Forest Associations (CFAs) that are legally recognized and registered with the Kenya Forests Service (KFS), giving communities the mandate to manage a given forest area. If the two community management mechanisms mentioned above are well coordinated, they have the potential to greatly assist with the management of the mud crab fishery. However, currently the BMU and CFA systems work independently to meet the needs of the mother ministries. The Forest Conservation and Management Act of 2016 does not mention BMUs, nor does the Fisheries Management and Development Act of 2016 mention CFAs, even though CFAs and BMUs were already in existence.

The adoption of the new constitution in 2010 provided for a devolved system of government. The fisheries sector was devolved to the county system of government and most of the fisheries management officers previously stationed in the former provinces and districts under the national government were moved to the County administration. Currently, there is no clear structure in place for the management of artisanal fisheries even though the Fisheries Management and Development of 2016 indicates that the County should be responsible for this, including the establishment of BMUs. In the absence of strong structures in County government, artisanal and inshore fisheries management and compliance is jeopardized. Further, the linkage between the national and county government is weak and leading to much time being required to harmonize and achieve the required management interventions for the fishery. Considerable effort is still needed to ensure that the existing policy and legal instruments are optimally utilized to manage fisheries in Kenya.

As observed in southeast Asia decades ago, all size classes of mud crab in Kenya and East Africa are also becoming the target of the fishery through the development of mud crab aquaculture (Le Vay, 2001; Onyango, 2002; Mirera, 2011). However, there are currently no policies or regulations in Kenya that focus on the collection of wild mud crabs (juveniles, sub-adults and adults) for aquaculture. The situation may be aggravated further by the increased global demand for soft shell mud crabs with no size requirements (Mirera, 2014). There is need for focused research to assist with management of the fishery to ensure sustainability (KCDP, 2013).

Effective management policies for the crab fishery may also need to address protection of under-sized, spawning, and moulting crabs to help reduce over-exploitation threats on the resource, while promoting sustainable utilization of the fishery.

Even though the CPUE for crabs has remained relatively stable, this may be misleading in terms of assessing stock status. Fishers target preferred crab habitats in the mangroves based on the traditional knowledge gained in the fishery, such as burrows or mangrove tree holes that are replenished during high tides. Based on the skewed nature of harvesting the fishery, the CPUE may not represent the status of the overall crab stocks since all sites are not fished equally while some other potential habitats may be unknown to the fishers (Mirera *et al.*, 2013). Therefore, diversity in potential crab fishing sites based on the local knowledge of fishers may require further research and harmonization for effective site-specific management of the fishery.

Management Recommendations

Currently, most artisanal mud crab fishers are not obliged to register as fishers since they never land their catch at designated landing sites. Most crab production estimates are taken at market outlets, which tend to under-estimate overall catch (Mirera, 2011). To improve on monitoring of the fishery, it is suggested that an effort is made to register all artisanal mud crab fishers in the same manner as in other fisheries, and as required in the Fisheries Management and Development Act of 2016. Also, that crab fishers land their catches at designated landing sites. These changes could be brought about by actively recognizing and including mud crab fishers in the local BMU management structures, as it is a unique fishery where compliance to regulations will require internal expertise and incentives.

It is evident that management of the mud crab fishery is complex and the relevant policies and regulations (National Ocean and Fishery Policy, 2008; Fisheries Management and Development Act, 2016; BMU Regulations; Forest Conservation and Management Act, 2016) have not been successful in achieving a well-managed fishery (Ludwig *et al.*, 1993). Managers may need to navigate the issues of effective management in the system by developing a strategic management matrix for the fishery, as argued by Perfilova and Alizade (2012). Deliberate effort is needed to harmonize the operations of national and county

governments so that compliance with the relevant legislation can be achieved. Further, there is need for capacity building in the county governments (as crucial partners) since they are required to make county fisheries management plans for inshore fisheries. However, the Fisheries Management and Development Act 2016 gives autonomous power to the Kenya Fisheries Service to approve the management plans developed by counties and guide the monitoring and surveillance of the fishery.

Acknowledgements

The KCDP Project is greatly appreciated for supporting the write-up of the status report through the Kenya Marine and Fisheries Research Institute (KMFRI). I also wish to thank the State Department for Fisheries and the Blue Economy (SDF & BE) currently referred to as Kenya Fisheries Service (KeFS) for the annual catch data used in the write up. The experimental data records on mud crabs harvested at different time periods provided by the Kwetu Training Centre, IFS and WIOMSA-MASMA projects is also appreciated. Pascal Thoya, a research scientist at KMFRI, is thanked for developing the map of the main mangrove areas along the Kenyan coast.

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Mangrove change detection, structure and condition in a protected area of eastern Africa: the case of Quirimbas National Park, Mozambique

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Abstract

Given the high dependence of coastal communities on natural resources, mangrove conservation is a challenge in Mozambique, even within several types of marine protected areas. This study assesses the condition of a mangrove forest in the Quirimbas National Park (QNP), where use by the local community is allowed with restrictions. Satellite imagery (1991 – 2013) and ground forest assessment were used to assess forest structure, conservation status, and regeneration potential of the forest. Random 10x10 m quadrats were set within the forest, for species identification, diameter at breast height (DBH), height measurement, assessment of levels of cut, and quality of the main pole. Young individuals were also counted to assess the regeneration potential.

The overall mangrove cover has increased by 10% from 11 244 ha to 12 348 ha between 1991 and 2013. The forest is dominated by *Ceriops tagal* and *Rhizophora muctonata*, but other 4 species were also identified (*Avicennia marina*, *Bruguiera gymnorhiza*, *Sonneratia alba*, and *Xylocarpus granatum*). Trees tend to be small in height and width (mean: 5.96 ±3.2 m and 7.69 ± 4.5 cm respectively), with a total density of 572 trees/ha. Statistical analysis indicated distinct patterns of transformation; the south with higher densities of crooked poles ($p < 0.05$) (369 trees/ha), and the north with higher density of stumps ($p < 0.05$) (250 stumps/ha). The north and south parts of the park also had higher densities of crooked than straight and semi-straight poles ($p < 0.05$). Natural regeneration was observed with adequate seedling/sapling density of between 36 733 to 126 133 saplings/ha. The results indicate that, despite being a protected area, the mangroves of the QNP are subject to pressure from the community, reflected in the loss of certain areas areas, and high density of cut trees and stumps. Appropriate measures are necessary to effectively protect these mangroves and meet conservation objectives.

Keywords: mangrove mapping, anthropogenic pressure, mangrove management, protected area

Introduction

Mangrove forests are unique and complex systems providing an array of ecosystem services to coastal communities such as firewood, timber, water purification, nursery grounds for fisheries, nesting sites for birds, cultural sites, and costal protection against extreme events (Kathiresan & Bingham, 2001; Alongi, 2002; FAO, 2007; Komiyama *et al.*, 2008, Cohen *et al.*, 2013). Furthermore, they have the potential for carbon sequestration, nutrient cycling, and worldwide contribution to climate change mitigation (Donato *et al.*, 2011; Giri *et al.*, 2011). Human-induced disturbances of mangrove ecosystems are related to direct exploitation for timber, fuel wood, aquaculture, urban

development (Taylor *et al.*, 2003; Williams *et al.*, 2007; Gilman *et al.*, 2008; Paling *et al.*, 2008), and to the deleterious consequences of climate change (eg sea level rise, flooding, erosion and sedimentation, fluctuating precipitation and temperature regimes, storms and cyclones) (McLeod & Salm, 2006; IPCC, 2013; Gilman *et al.*, 2008).

Despite their recognised importance, mangrove forests are among the most threatened ecosystems worldwide (Valiela *et al.*; 2001) with 35% of the original global area being degraded or destroyed since 1980, and current global rates of loss running between 1 - 2% per annum. According to several studies, 11 of the 70 mangrove species (or 16%) are classified as threatened, and are on the IUCN Red List (Valiela *et al.* 2001; FAO, 2007; Donato *et al.*, 2011; Cohen *et al.*, 2013).

Mangrove forests in Mozambique rank 13th worldwide and third in Africa in terms of cover area, with around 300 000 ha (Giri *et al.*, 2011). They occur on protected shorelines, deltas and estuaries that are distributed all along the coastline (Barbosa *et al.*, 2001; Hoguane, 2007). Eight mangrove species occur in Mozambique (Barbosa *et al.*, 2001) with the dominant species being *Avicennia marina* (Forssk.) Vierh., *Bruguiera gymnorhiza* (L.) Lam., *Ceriops tagal* (Per.) C. B. Robinson, *Rhizophora mucronata* Lam. and *Sonneratia alba* Smith. Others species are *Heritiera littoralis* Aiton, *Lumnitzera racemosa* Willd. and *Xylocarpus granatum* Koenig (Barbosa *et al.*, 2001; Macamo *et al.*, 2016a).

In Mozambique mangroves are mostly used for building, firewood, fish trapping and medicine (Barbosa *et al.*, 2001). Ecologically they provide protection to the shoreline and act as fish nurseries for commercially important fish and shrimp (Duke, 2001). The major threats to mangroves in Mozambique are related to clearance of mangrove forests for agriculture, aquaculture, salt production, and diminishing freshwater flow to mangroves due to dam constructions, high development along the Mozambican coast, and climate change impacts (Saket & Matusse, 1994; Barbosa *et al.*, 2001; Macamo *et al.*, 2016a).

Analyses of forest cover change, structural characteristics, species composition, and regeneration patterns can shed light on the degree of damage inflicted on forest ecosystems by the joint influence of man-induced and climate-related disturbances. Similarly, understanding the ecological status, compositional, functional and structural diversity, is imperative to obtaining the necessary information required for planning management interventions (Satyanarayana *et al.*, 2011).
Remote sensing techniques and forest structure assessments have been adopted increasingly to estimate mangrove forest area, productivity, species distribution and density (Satyanarayana *et al.*, 2011; Kirui *et al.*, 2013; Fatoyinbo & Simard, 2013). Commonly, satellite imagery used in forestry include SPOT, Landsat Thematic Mapper and Enhanced Thematic Mapper (ETM), Quickbird, IKONOS, and Shuttle Radar Topography Mission (SRTM) (Fatoyinbo & Simard, 2013; Hirata *et al.*, 2014; Macamo *et al.*, 2016b). These techniques can easily quantify changes in forest structure over time, and monitor dynamics (Fatoyinbo *et al.*, 2008). Low resolution imagery such as Landsat (Shapiro *et al.*, 2015) are adequate to capture cover over larger areas, whereas higher resolution such as Quickbird and IKONOS, are used to detect cover changes in small areas and to document mangrove zonation up to individual species. 3D structure can be accomplished using imagery from Lidar, ICESat/GLAS (Ice, Cloud, and land Elevation Satellite /Geoscience Laser Altimeter System combined with SRTM (Shuttle Radar Topography Mission)); these drawn from Landsat imagery as documented (Fatoyinbo & Simard, 2013).

Quirimbas National Park (QNP) includes 6 districts of Cabo-Delgado Province, northern Mozambique, covering an area of 7 506 km², where 5 984 km² are terrestrial mainland (with inland *inselbergs*), and 1 522 km² are coastal and marine habitats. The park contains four eco-regions of worldwide conservation importance, including South-east African Coastal Forest, East African Mangrove, miombo forest and Eastern Savannah (Gabrie *et al.*, 2008). The QNP was created in 2002 and is considered as a regional and global priority area for biodiversity conservation (MITUR, 2009, MITUR, 2014).

Around 160 000 people live permanently within the QNP distributed in 90 villages, and approximately 20% of the population is located along the coastal zone. Over 95% of the coastal population is economically dependent on natural resources, particularly wood exploitation, agriculture and small-scale fisheries (INE, 2013; MITUR, 2014). Due to the high levels of natural resource dependence, anthropogenic impacts on critical ecosystems are of a key concern within QNP. The QNP has a system of zoning that includes: i) full protection zones, where resource extraction is prohibited; ii) community development zones in which sustainable harvesting is permitted for the benefit of fishers;

and iii) special use zones, which include Saint Lazarus Banks, reserved for sports fishing (Gabrie *et al.*, 2008).

The Management Plan for Quirimbas National Park includes several measures to promote human welfare and sustainable use of natural resources within the park. Mangrove management measures include appropriate use and protection of mangrove ecosystems (Law 10/1999, from July 7th – Forestry and Wildlife Law; and Law 16/2014 from 18th July – Conservation Law). Exploitation of mangrove resources is only allowed for local use (firewood, and timber for construction of boats and houses) and strictly prohibited for commercial purposes; harvesting of mangroves is prohibited in the Total Protection Zones (MITUR, 2014).

This study aimed to analyse temporal changes in mangrove cover from 1991 to 2013; assess mangrove structural parameters, conservation status, as well as natural regeneration potential. The information generated from this study will inform the Park Authorities in designing a co-management programme for mangroves and fisheries resources in QNP, and build-up information for ecosystem-based management of coastal and marine ecosystems in QNP.

Material and Methods

Study Area

Quirimbas National Park (QNP) is located in Delgado Province, northern Mozambique, and is characterized

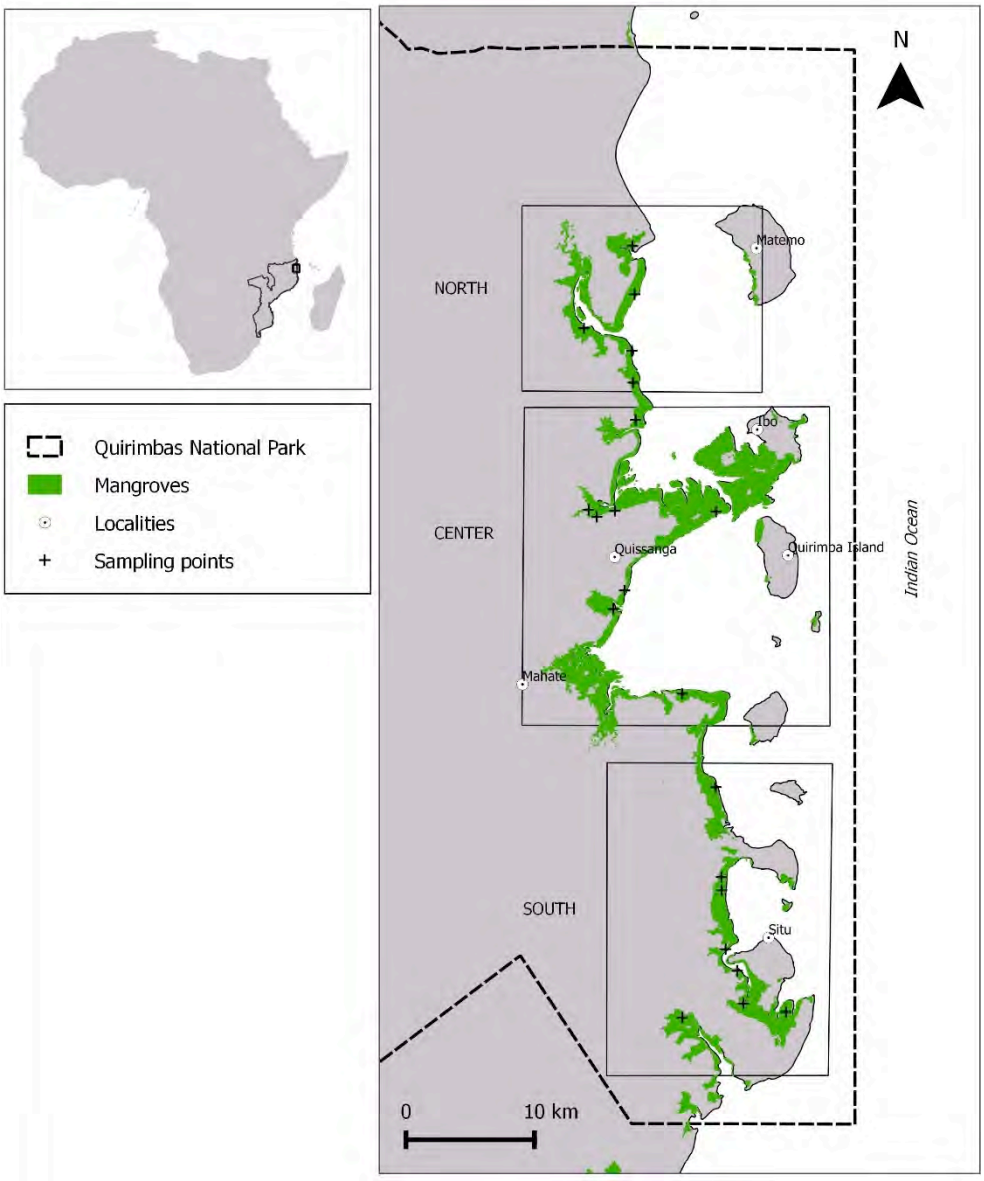

Figure 1. Geographic Location of Quirimbas National Park.

by a relatively narrow coastal plain with few rivers, a coastline of sandy beaches, mangrove forests, seagrass meadows, fringing coral reefs, scattered islands, and a narrow continental shelf (S: 12 ° 00 '00 "and 12 ° 55' 04" and E: 39 ° 10 '00 "and 40 ° 39' 44" East; Fig. 1) (MITUR, 2003). The climate in the study area is tropical with two distinct seasons during the year; a wet and warm season (November to April), and a drier and cooler season (May to October). The mean temperatures vary between 25°C and 27°C and rainfall is restricted to the warm season (MITUR, 2014). The tidal range is an average of 2.4 m and the coast is subject to occasional tropical cyclones (4 in the past 16 years) (INGC, 2009).

Mangrove Mapping

In order to develop information on mangrove extent over time within QNP, Landsat images from three epochs (August, 1991; May, 2002; and May, 2013) were used. The imagery was acquired from the US Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) website (www.glovis.usgs.gov) repository. Imagery with low cloud coverage scenes (less than 10%) were selected to minimize differences in mangrove cover due to seasonal effects. Imagery classification consisted of a hybrid process, which included an unsupervised algorithm, followed by a supervised process. The unsupervised process used a k-mean algorithm in order to provide the

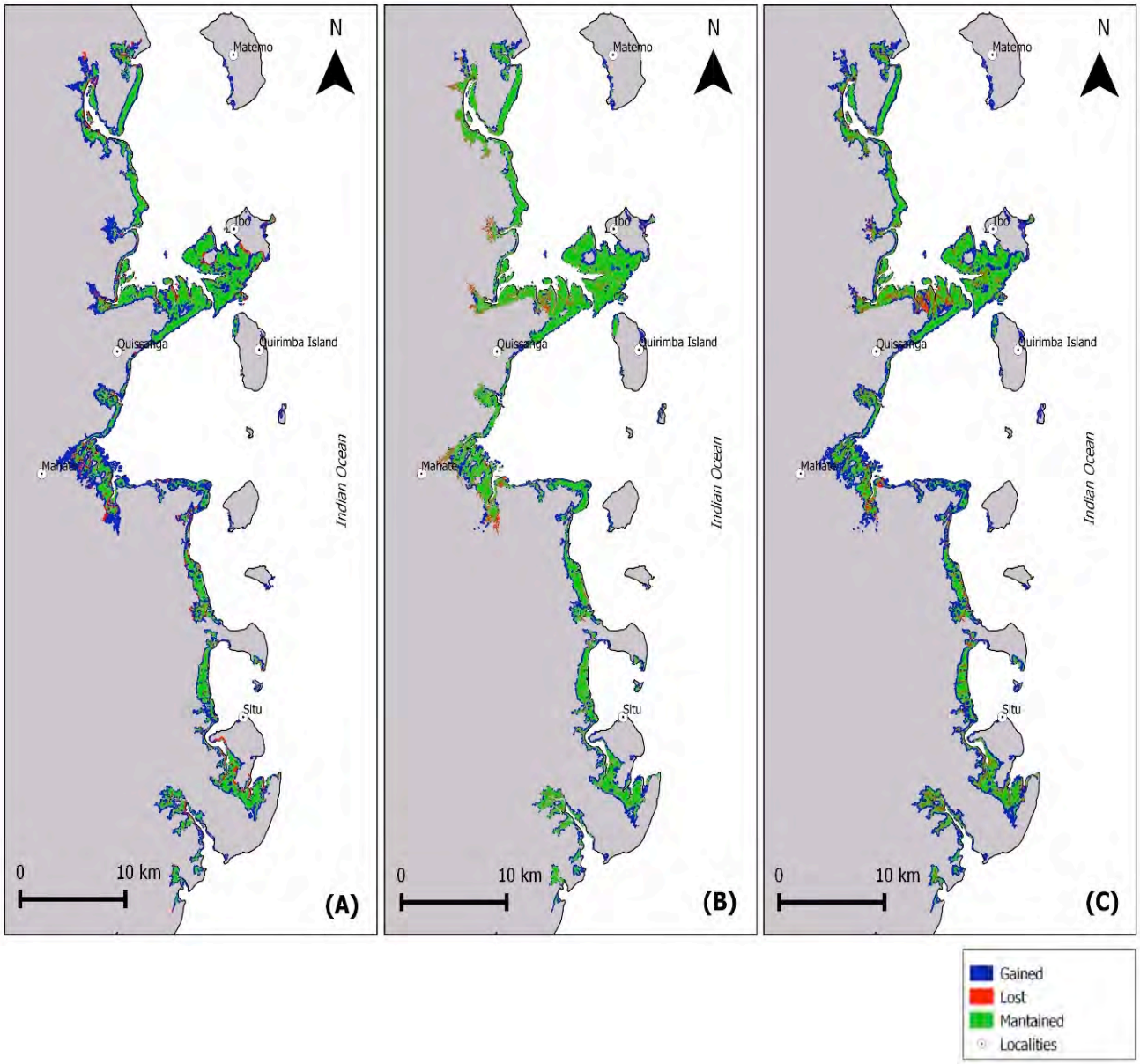

Figure 2. Detailed maps of mangrove cover change within Quirimbas National Park in 1991 (A), 2002 (B) and 2013 (C).

Table 1. Mangrove cover area dynamics from 1991 to 2013 in the Quirimbas National Park.

	Timeline			
Variables	**1991**	**2002**	**2013**	**Net change**
Area extent (ha)	11 244	12 812	12 348	
Cover variation (gain and loss) (ha)	-	1 568	- 464	+1 104
Annual change percentage (%) (ha)	-	1.27	- 0.33	9.8%

statistical distribution of spectral classes for each image. Land use classes were assigned to spectral classes, and ground-truthing work undertaken to train and validate the supervised algorithm. Some samples of land use classes where acquired using Google-earth high-resolution imagery. Maximum likelihood supervised algorithm was used in a second stage classification process resulting in a land use classification for each imagery. The main land use classes identified were: mangrove forest; mud; sand; water; and terrestrial areas. Confusion Matrices and classes accuracy assessment were derived for each image classification. The classification scheme resulted in maps of mangrove vegetation cover between 1991 and 2013, and 2002 to 2013.

The distinction between potentially confusing areas of mangrove and terrestrial vegetation, including ecotone areas, and the discrimination of patches of terrestrial vegetation within areas of mangrove forest, was based on visual interpretation of the imagery available from Google-earth and from ground-truthing information.

Forest Assessment

To assess the forest structure, condition, quality, and regeneration pattern within QNP, the park was systematically classified into three sampling areas, each reflecting similar proportions of mangrove distribution: (i) North - Macomia and Darumba; (ii) Center - coastal area of Quissanga, Ibo and Quirimba Island; (iii) South - Arimba and Situ (Fig. 1).

A total of 31 (10 x 10 m^2) plots were randomly set in the 3 subsampling areas (based on a grid of 1 km intervals). All individual mangrove trees inside the

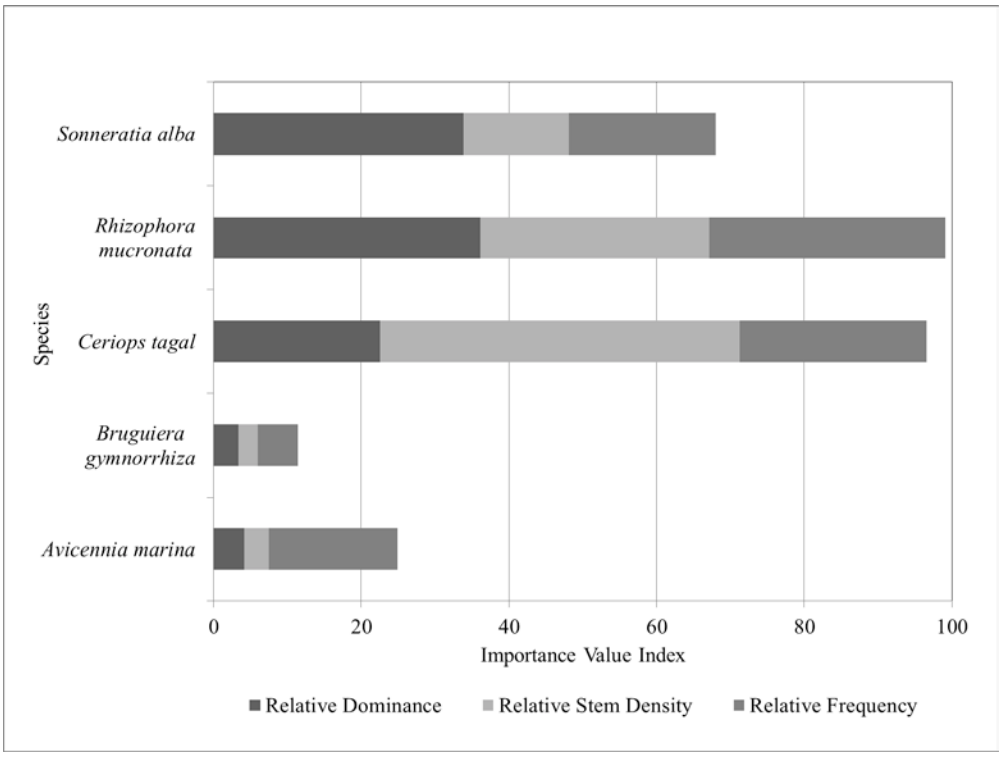

Figure 3. Importance Value Index of mangrove species in QNP.

Table 2. Importance value (IV) of the mangroves within QNP in the 3 sub-sampling areas. All adult trees with (DBH) > 2.5 cm were measured.

		Relative Values (%)			
Region	**Species**	**Dominance**	**Density**	**Frequency**	**IV**
North	*Avicennia marina*	4.15	3.32	17.47	24.94
	Bruguiera gymnorhiza	3.32	2.69	5.42	11.43
	Ceriops tagal	22.57	48.7	25.3	96.57
	Rhizophora mucronata	36.14	31.01	31.93	99.08
	Sonneratia alba	33.82	14.27	19.88	67.98
Centre	*Avicennia marina*	11.34	13.62	19.29	44.26
	Bruguiera gymnorhiza	1.97	1.56	7.29	10.82
	Ceriops tagal	8.69	23.66	20	52.35
	Rhizophora mucronata	43.33	44.29	32.24	119.85
	Sonneratia alba	34.26	16.4	20.47	71.13
	Xylocarpus granatum	0.41	0.47	0.71	1.59
South	*Avicennia marina*	6.11	7.33	12.15	25.59
	Bruguiera gymnorhiza	1.76	3.23	14.98	19.97
	Ceriops tagal	18.44	47.51	28.34	94.29
	Rhizophora mucronata	64.08	39.63	37.25	140.95
	Sonneratia alba	9.62	2.31	7.29	19.21

Total areas: North – 0.21 ha; Center – 0.62 ha and South 0.32 ha. Number of individuals sampled: North - 648, Center – 2040 and South -1315.

quadrates were counted, identified to species, measured for diameter at breast height (DBH) ≥ 2.5cm, and tree height (m) estimated (Kairo *et al.*, 2002; Komiyama *et al.*, 2005; Bandeira *et al.*, 2009; Kauffman & Donato, 2012).

From the data collected information was derived on species composition, species diversity, structural parameters, and community indices including basal area (m^2/ha), mean stand height (meters), stem density (stems/ha), relative frequency (%), relative dominance (%), importance value (I.V.), and complexity index (C.I.) which was calculated as the product of number of species, basal area (m^2/ha), mean stand height (m) and density (number of stems/ha) following the methodology described by Kairo *et al.* (2002) and Dahdouh-Guebas & Koedam (2006).

To assess forest condition all individuals were counted and grouped into five degradation categories. These were: intact, for trees with no sign of cut; partially cut, for those with one or more branches which had been cut, but with the main trunk intact; severely cut, with most branches cut; stump, for those whose main trunk had been cut; and die back, for those dead from natural causes (Kairo *et al.*, 2001; Bandeira *et al.*, 2009). Diameter of stumps was measured to estimate preferred sizes for cutting. The same measurements of dead standing trees were taken as for live trees.

The usage quality of poles in the forest was assessed based on the form of the lead stem, which was categorized either as form 1, 2 or 3. Form 1 stems denotes those whose lead stem are straight and therefore excellent for construction, while Form 2 stems represent poles that need slight modification to be used for construction. Form 3 stems are crooked poles which are unsuitable for construction (Kairo *et al.*, 2001; Kairo *et al.*, 2008).

Regeneration status was assessed by species identification and counting individuals (DBH less than 2.5 cm). The frequency (%) of each species was recorded and juveniles were grouped in 3 regeneration classes (RC) based on height, as RC I, II or III. Seedlings less than 40 cm in height were classified as RCI; saplings

Table 3. Structural attributes of the mangroves in Quirimbas National Park per subsampling area.

Region	Specie	Diameter (cm)	Height (m)	BA (m2/ha)	Density (stem/ha)	No of Species	CI*
North	*Avicennia marina*	12.64 ± 5.31	6.03 ± 2.08	2.73	102 ± 44	5	1.5
	Bruguiera gymnorhiza	7.79 ± 3.10	6.50 ± 1.88	5.09	83 ± 56		
	Ceriops tagal	6.01 ± 0.22	3.17 ± 0.66	7.99	1.507 ± 599		
	Rhizophora mucronata	8.29 ± 1.40	6.52 ± 1.54	10.39	956 ± 291		
	Sonneratia alba	12.38 ± 3.01	6.23 ± 0.98	17.29	442 ± 295		
Centre	*Avicennia marina*	8.61 ± 0.90	6.61 ± 0.93	5.18	452 ± 202	6	1.6
	Bruguiera gymnorhiza	8.27 ± 1.48	6.51 ± 0.93	2.43	52 ± 21		
	Ceriops tagal	5.28 ± 0.67	4.80 ± 0.98	3.97	784 ± 264		
	Rhizophora mucronata	7.70 ± 0.73	7.16 ± 0.63	12.14	1.468 ± 275		
	Sonneratia alba	12.03 ± 1.00	8.22 ± 0.89	14.57	544 ± 206		
	Xylocarpus granatum	7.82 ± 0.00	7.95 ± 0.00	5.11	16 ± 16		
South	*Avicennia marina*	11.53 ± 2.81	6.21 ± 1.94	6.19	294 ± 252	5	2.2
	Bruguiera gymnorhiza	7.21 ± 1.45	4.79 ± 0.59	1.19	130 ± 47		
	Ceriops tagal	5.11 ± 0.36	3.41 ± 0.23	6.79	1.908 ± 494		
	Rhizophora mucronata	8.09 ± 1.08	6.02 ± 0.64	18.53	1.592 ± 336		
	Sonneratia alba	16.09 ± 1.91	7.96 ± 1.29	15.57	93 ± 50		

*Complexity Index
**Values are mean ± standard error, SE.

between 40 and 150 cm height were classified as RCII, while RCIII was for all small trees with height greater than 1.5 m but less than 3.0 m as described by Kairo *et al.* (2002), Kairo *et al.* (2008) and Bandeira *et al.* (2009).

All data (DBH, height, tree quality, forest condition and regeneration) were subjected to tests of normality and homogeneity variances. One-way ANOVA at 0.05 probability tests were performed to test differences in stocking densities, DBH, and height (m) between sites (north, centre and south). Non-parametric data were subjected to the Kruskal-Wallis test following the procedures described by Kairo *et al.* (2001) and Dahdouh-Guebas & Koedam (2006).

Results

Mangrove Mapping

Mangroves occur extensively within the maritime perimeter of the QNP with the exception of some islands peninsulas. Based on results of this research, the total estimated area of mangroves in the QNP was 12 348 ha, a net increase of about 1 104 ha (or 9.8% of the initial area) from 1991 to 2013 (Fig. 2), with an annual increase of 50 ha/year. While there was an overall net increase in mangrove cover from 1991 to 2013, there was a net loss of 464 ha in specific areas from 2002 to 2013 (Table 1). The area weighted accuracy assessment for the Landsat change analysis showed an overall accuracy of 85% (originated from Confusion Matrix) for current mangrove cover.

Mangrove Forest Structure

A total of 4 003 adult individuals were sampled in 3 sub-sampling areas (north, centre, and south) within the mangrove forests of QNP. A total of 6 mangrove species were found, namely *A. marina, B. gymnorhiza, C. tagal, R. mucronata, S. alba*, and *X. granatum*. Relative dominance, density, frequency and importance values of these species are shown in Fig. 3 and Table 2.

Based on species importance values, *R. mucronata*, *C. tagal* and *S. alba* were the most abundant species within QNP (Table 2). *X. granatum* was very rare with only a few individuals sampled (this species was not included on the statistical analysis). *A. marina, B. gymnorhiza* and *C. tagal* were often found in landward

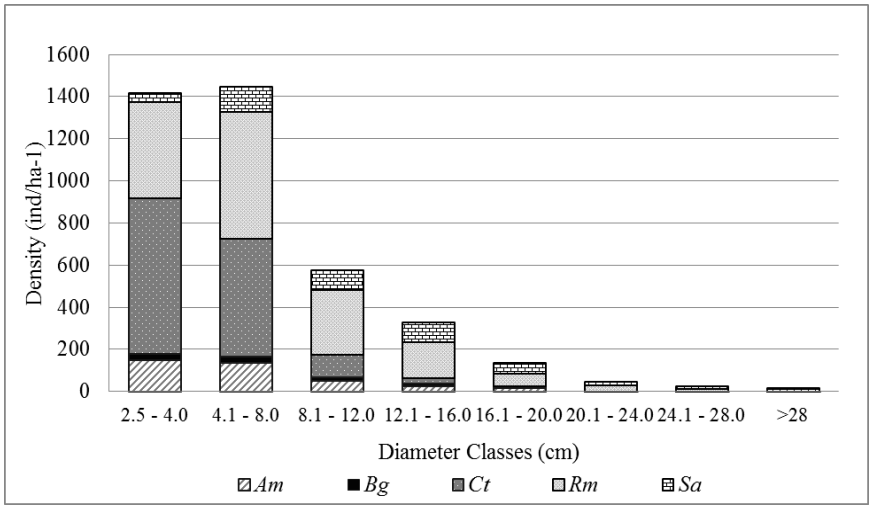

Figure 4. Species diameter distribution classes in QNP.

areas and mixed with *R. mucronata* which was widespread and also found on regularly flooded areas and small creeks. *A. marina* was also distributed on seaward areas in association with *S. alba*.

Stand density, DBH, tree height values per species, and sampling areas are presented in Table 3. DBH varied between 5.1 and 16 cm, and height from 3.1 to 7.9 m. Despite the high DBH, dwarf stands were commonly found in the forest within highly saline areas. When comparing species, mean minimum and maximum diameter ranged between 5.11 cm (for *C. tagal*) and 16.09 cm (*S. alba*), while mean height varied between 3.41 m (*C. tagal*) and 8.22 m (*S. alba*). The tallest trees observed were *S. alba* (8.22 m), followed by *X. granatum* (7.96 m) and *R. mucronata* (7.16 m).

The mean stem density of individuals in the forests of the QNP was 579 stems/ha. The species abundance shows some variation amongst species accounting for

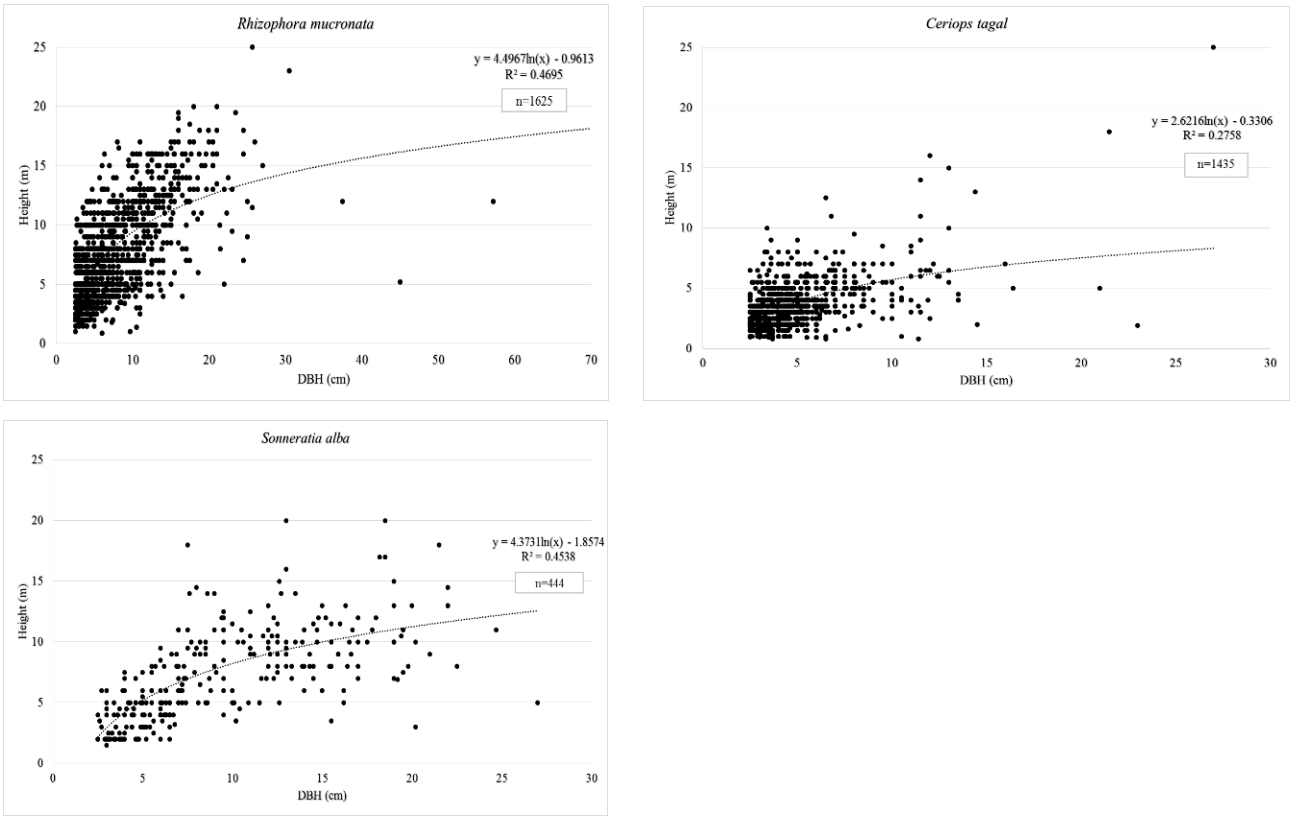

Figure 5. Height-diameter distribution of *Rhizophora mucronata*, *Ceriops tagal* and *Sonneratia alba* within QNP.

1 406, 1 251, 393, 338, 80 and 8 stems/ha for *R. mucronata*, *C. tagal, S. alba*, *A. marina, B. gymnorhiza*, and *X. granatum*, respectively.

There was significant differences in the stem density between species and subsampling areas ($p< 0.05$). The variation in complexity index between areas in the QNP is evident, with the south region recording a higher index (Table 3).

Fig. 4 shows species diameter class distribution in the QNP. Overall, the forest had high densities of trees in the lower diameter size classes (below 8 cm). *C. tagal* was characterised by high densities of trees in the low size class (2.5 – 4.0 cm); *R. mucronata* had a wide distribution of stems in the low-mid and high classes (4.1 – 24.0 cm), and *S. alba* dominated the high size class (24.0 – >28.0 cm). The observed stem size distribution displays some selective harvesting of stems, within classes (8.0 - 16.0 cm). Preferred species for cutting were *C. tagal*, *R. mucronata*, and *A. marina* (Fig. 4).

Fig. 5 shows scattergrams of height – diameter distribution of high importance value (IV) species in the QNP.

Mangrove Cut Condition and Pole Quality

The mangrove forest cut condition and quality of existing poles is represented in Fig. 6 and 7 respectively. Different densities were found amongst categories (Table 4): partially cut (PC) with 231 stems/ha; severely cut (SC) with 395 stems/ha; stump (S) with 188 stems/ha; and die back (DB) with 171 stems/ha. The intact stands (I) had the highest mean density in the entire research area with 941 stems/ha. There are statistical differences between the densities of all categories of cut conditions (<0.05).

Partially and severely cut trees had high densities in the north and south of with 225 stems/ha, and 395 stems/ha, respectively. These categories showed a distribution pattern in sampling areas, and the entire forest, as displayed in Fig. 6 below. A higher density of stumps was found in the north with *C. tagal* (636 stem/ha), while the highest die back was found in the south region for *C. tagal* (461 stem/ha). In the north and centre regions of QNP, *R. mucronata* and *C. tagal* appeared to be the preferred species for cutting, whereas in the south it was *A. marina.*

Semi-straight and crooked poles dominated over straight poles throughout the park. The highest density of semi-straight poles (880 stems/ha) was found in the centre region (Fig. 7), while the southern region accounted for the highest density of straight and crooked poles (504 stems/ha and 639 stems/ha, respectively). These differences are however not statistically significant ($p > 0.05$). At species level, half of the total poles of *A. marina* and *S. alba* were crooked (Table 5), and the majority of intact and semi-intact poles were recorded from *C. tagal*. Half of *Rhizophora* sampled were semi-intact.

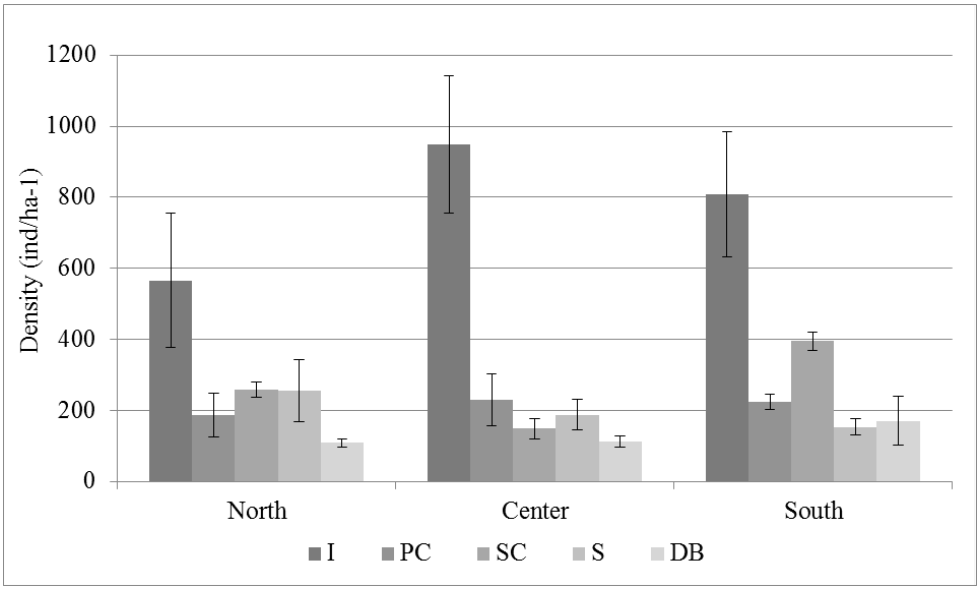

Figure 6. Mangrove forest density of trees of different cut levels in the 3 sampling areas (north, centre and south) within QNP. Classes are described as follows: (I) Intact; (PC) partially cut; (SC) severely cut; (S) stump and (DB) die back.

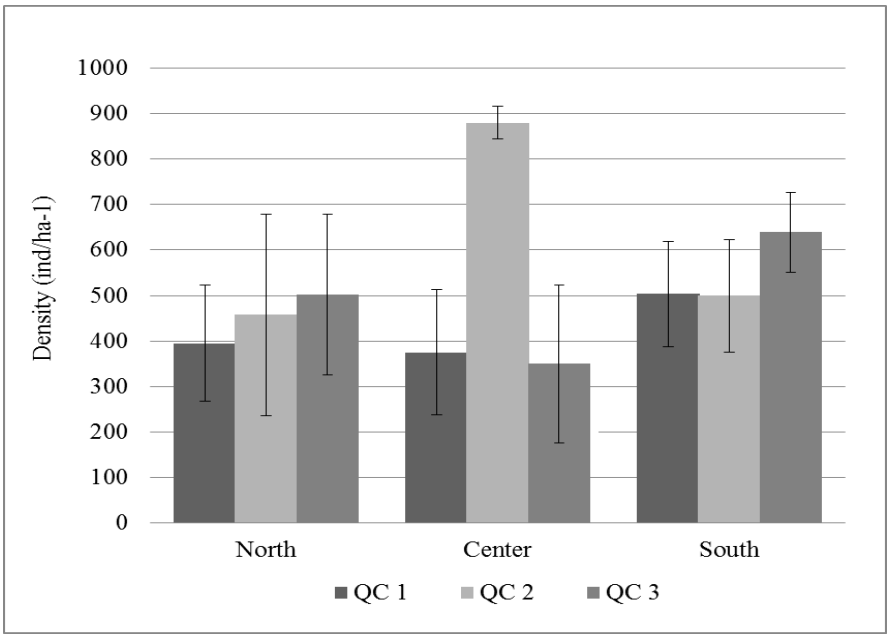

Figure 7. Quality pole distribution in the 3 sampling areas (regions). QC1 – represents straight poles suitable for building, and QC 2 - represents poles that need some modification prior to use in construction, while QC 3 - represents crooked poles unsuitable for construction (Kairo *et al.* 2001).

Regeneration

Natural regeneration was observed at all sites within the QNP. On average, total juvenile densities ranged from 36 733 – 126 133 juveniles/ha, with *R. mucronata* representing the highest density with 180 400 juveniles/ha as indicated in Table 6. Statistical differences between regeneration classes were not significant ($p > 0.05$).

The highest juvenile density was observed in the centre sampling area (286 200 juveniles/ha) and southern parts (202 500 juveniles/ha), while the north had the lowest regeneration densities of 93 033 juveniles/ha. When comparing regions, there were significant differences between species within regions ($p < 0.05$). Comparing species, the highest density was observed in *R. mucronata* (180 400 juveniles/ ha) and *C. tagal* (134 600 juveniles/ha) followed by *A. marina* (34 767 juveniles/ha), *B. gymnorhiza* (4 933 juveniles/ha) and *S. alba* (1 000 juveniles/ha).

The regeneration ratios (RCI: RCII: RCIII) for the entire forest was 2:1:1, 1:2:1 for the north, 1:1:1 for the center, and 2:1:1 for the south region. The regeneration did not reach the effective rate of stocking of 6:3:1 for juveniles, as described by Kairo *et al.* (2002). However, based on seedling densities, QNP mangroves can be considered to potentially have good regeneration capacity. The centre and south regions present the same pattern of species distribution and densities.

Discussion

The temporal analyses of mangrove cover within the QNP show an overall 10% increase in mangrove cover over the time period of 22 years (1991 to 2013),

Table 4. Forest condition class distribution in QNP showing the densities per ha and percentage (in brackets) composition per species. Categories are described as follows: (I) Intact; (PC) partially cut; (SC) severely cut; (S) stump and (DB) die back.

Condition	I	PC	SC	S	DB
A. marina	420 (26.2)	318 (19.8)	671 (41.8)	119 (7.4)	77 (4.8)
B. gymnorhiza	294 (31.1)	150 (15.9)	250 (26.5)	183 (19.4)	67 (7.1)
C. tagal	1887 (61.4)	330 (10.7)	180 (5.9)	442 (14.4)	234 (7.6)
R. mucronata	1268 (59.0)	255 (11.9)	151 (7.0)	318 (14.8)	158 (7.3)
S. alba	444 (30.7)	236 (16.3)	386 (26.7)	132 (9.1)	250 (17.3)
X. granatum	333 (100.0)	-	-	-	-

Table 5. Quality class distribution in QNP showing the densities per ha and percentage (in brackets) composition per species.

Quality Class	1	2	3
A. marina	256 (21.8)	313 (26.6)	606 (51.6)
B. gymnorhiza	216 (28.4)	262 (34.4)	283 (37.2)
C. tagal	1094 (38.7)	1073 (38.0)	658 (23.3)
R. mucronata	469 (23.4)	1027 (51.3)	506 (25.3)
S. alba	215 (19.4)	347 (31.2)	548 (49.4)
X. granatum	-	1000 (100.0)	-

despite the slight decrease observed between 2002 and 2013. Areas showing an increase and decrease of mangrove cover were visible in the field. For example, newly colonized areas had a high density of juveniles from all tree regeneration classes, whilst decrease and degradation was depicted by high levels of mortality (eg several dead trees often found along the shoreline and inner areas of the mangrove forest).

Increases in mangrove cover in Mozambique and elsewhere have been related to factors such as sediment accretion, increased salinity, upstream inundation of salt water due to changes in rain patterns, and the natural dynamic of the system (Giri *et al*., 2007; Eslami-Andargoli *et al*., 2009; Macamo *et al*., 2015; Shapiro *et al*., 2015). Cabo Delgado Province is among those that has shown less variation in mangrove area

Table 6. Juvenile density (juveniles/ha) in QNP

Region	Species	Ind/ha			Total Ind/ha
		RC I	RC II	RC III	
		0 - 40 cm	40.1 - 150 cm	150.1 - 300 cm	
North	*Avicennia marina*	1 333	1 700	1 067	4 100
	Bruguiera gymnorhiza	0	0	700	700
	Ceriops tagal	32 800	4 267	6 667	43 733
	Rhizophora mucronata	3 867	11 800	28 200	43 867
	Sonneratia alba	233	300	100	633
	Total	**38 233**	**18 067**	**36 733**	**93 033**
Centre	*Avicennia marina*	32 667	400	1 700	34 767
	Bruguiera gymnorhiza	400	633	3 900	4 933
	Ceriops tagal	42 600	9 500	13 000	65 100
	Rhizophora mucronata	50 267	72 233	57 900	180 400
	Sonneratia alba	200	300	500	1 000
	Total	**126 133**	**83 067**	**77 000**	**286 200**
South	*Avicennia marina*	4 667	400	400	5 467
	Bruguiera gymnorhiza	200	200	300	700
	Ceriops tagal	66 033	26 267	42 300	134 600
	Rhizophora mucronata	28 367	18 700	14 433	61 500
	Sonneratia alba	233	0	0	233
	Total	**99 500**	**45 567**	**57 433**	**202 500**

in Mozambique (Fatoyinbo *et al*., 2008; Ferreira *et al*., 2009), possible due to the remoteness and low population density in the province in general (Ferreira *et al*., 2009). Being in a protected area, the mangroves of the QNP are expected to be under some degree of protection from human transformation, which would allow expansion from natural processes. However, in the regions of Sundabarns (India and Bangladesh), protection and appropriate management measures resulted in little to no-change in forest area (Giri *et al*., 2007). Globally, unlike the trend in the QNP, mangrove loss is more expected than expansion (Valiela *et al.*, 2001; Mohamed *et al.*, 2008; Giri *et al.*, 2011; Kirui *et al.*, 2013; Bosire *et al*., 2016).

In general, the forest complexity index was low, indicative of a young forest, and possible natural or anthropogenic impacts. Low complexity index and dominance of small trees in the forest was also observed in severely impacted peri-urban forests in Kenya (Kairo *et al*., 2002; Mohamed *et al*., 2008) and other regions of Cabo Delgado Province (Bandeira *et al*., 2009). Natural regeneration was observed extensively in QNP, contrasting with low recruitment in human impacted mangrove areas such as those in Kenya (Kairo *et al.*, 2002; Mohamed *et al.*, 2009). In the QNP seedlings were frequently found growing in clusters close to the mother tree, similar to the situation documented in Kenya by Bosire *et al.* (2005), this possibly providing an advantage against predation, diseases, erosion and sedimentation (Olagoke *et al*., 2013). Furthermore, seedlings were abundant in forest canopy gaps similar to what has been found by Duke (2001) and Bosire *et al.* (2005) in other regions. Such canopy gaps are common in mangroves and are the result of natural parameters such as increased light and temperature, high water evaporation rates, and high pore-water salinity impacting on the dispersal, survival and growth of seedlings.

Conclusions

The geo-spatial data generated from this study revealed an overall increase of 10% of the area covered by mangroves (11 244 to 12 348 ha) in the QNP for the period from 1991 to 2013). Signs of anthropogenic pressure on forest structure, condition, and pole quality were noted. The high density of juveniles (36 733 – 126 133 juveniles/ha) corroborates with mangrove forest area increase at QNP.

Structural data (low complexity index, small tree dominance, die back) indicate that the forest is under pressure. Nonetheless, there appears to be feasible potential for natural regeneration. Despite the QNP being a protected area, anthropogenic use of mangroves was noted in several areas. There was also some mangrove die back evident along the shoreline. This study provides a baseline that can be used to reinforce the current QNP Management Plan (2014 -2019), and to identify additional research needs such as high resolution mapping to detail both anthropogenic and natural impacts and other related parameters affecting mangrove structure and condition. Community Based Natural Resources Management (CBNRM) focusing on mangrove forests and the surrounding ecosystems, may be the catalyst needed to encourage socio-ecological mangrove research within the QNP.

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Evaluating the fisheries potential of solar salt works reservoirs at Ungwana Bay, North Coast, Kenya

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Abstract

Artisanal fisheries are important livelihoods for coastal communities in many developing countries, where uncontrolled fishing can easily lead to depleted stocks in nearshore waters. Man-made reservoirs associated with solar salt works along the coast of Ungwana Bay provide alternative fishing grounds for local fishers unable to venture far offshore. We evaluated the fisheries potential of salt works reservoirs through regular catch assessment surveys at Gongoni, Kurawa and Marereni reservoirs between January 2015 and February 2016. Fishing effort and catch data were analyzed for seasonal patterns in catch composition and catch rates. Prawn seine nets were the dominant fishing gear used in the three reservoirs, augmented by traps at Kurawa. A total weight of 4.02 tonnes consisting of 49 finfish and 9 crustacean species was sampled. *Metapeneaus monoceros* was the most abundant species at Gongoni and Marereni, and *Oreochromis mossambicus* dominated at Kurawa. Non-metric multidimensional scaling (nMDS) showed distinct catch composition in all reservoir / season combinations for prawn seines. Highest species diversity occurred at Marereni during northeast monsoon conditions, whereas lowest diversity occurred at Gongoni during the southeast monsoon. Catch composition of prawn seines and traps differed at Kurawa. There was a significant difference in catch rates (kg/fisher.hr-1) between reservoirs, but not between seasons. Fisheries production in reservoirs was therefore affected more by their location and the gear type used, rather than by season.

Keywords: Catch composition, Catch rate, Solar salt works reservoirs, Prawn seines

Introduction

Solar salt works reservoirs are anthropogenic supratidal habitats exploited for sea salt, which becomes progressively concentrated by evaporation (López *et al*., 2010). These systems are considered the most efficient converters of solar energy into an inorganic commodity (Sedivy, 2009). Along the Ungwana Bay on the north coast of Kenya, there are a total of six salt production companies, namely Krystalline Salt Limited, KEMU Salt Packers Production Limited, Kurawa Industries Limited, Malindi Salt Works, KENSALT Limited, and Mombasa Salt Works Limited (KNCHR, 2006). Solar salt works reservoirs are unique man-made wetlands that feed a network of shallow ponds (salt pans) for salt making. The co-existence of regular and hyper-saline waters in the network of ponds supports important biological systems as well as providing refuge for aquatic life (Davis, 2009). Utilization of these ponds for other activities apart from salt production has been reported in many parts of the world. For example, in India, mariculture has been conducted in the salt works where water reservoirs and salt pans are utilized for prawn culture. According to Rao *et al*., (1988) this practice not only increased the prawn production and enhanced food security but also increased income levels for both the salt industry

owners and the local communities. In Kenya, the culture of brine shrimp (*Artemia franciscana)* has been practiced on a small-scale and non-commercial basis alongside salt production in the salt pans since the 1980s when the species was first introduced into the Kurawa salt works (Kaiser *et al*., 2006). In addition, the salt works reservoirs have created foraging grounds for migratory birds including piscivorous and filter feeding bird species such as flamingoes and pelicans (López *et al*., 2010).

Generally, these man-made reservoirs are not constructed for fisheries production as the main objective. However, in the process of operation, fisheries emerge as a crucial secondary resource with income from these activities often exceeding that of the primary purpose of the reservoirs (Rocha *et al*., 2011). From the time of their establishment, reservoirs of the salt works in Ungwana Bay have been popular fishing grounds for local fishers who lack appropriate crafts to venture into the open sea. High abundance of penaeid prawns and other species such as *Oreochromis mossambicus,* capable of surviving wide salinity ranges, have been reported to contribute significantly to the total landings in Ungwana Bay (KMFRI, 2015). The solar salt works reservoirs are therefore essential fishing grounds for artisanal fishing and the main source of animal protein (Beard *et al.*, 2011) for many low income communities living near these resources. The reservoir fisheries in the solar salt works are however unique, and different from other artisanal fisheries in the bay. Unlike the inshore and open sea where artisanal fishing activity is higher during the dry northeast monsoon (NEM) season and lower during the wet southeast monsoon (SEM) season due to rough sea conditions (McClanahan, 1988), fishing activities in the reservoirs largely depend on the operations of the salt works which run throughout the year, and hence are less affected by the seasons (Munga, 2013). This study describes and characterizes the fisheries of the solar salt works reservoirs through assessment of the seasonal patterns in catch composition and catch rates.

Materials and Methods

Study Area

The Ungwana Bay on the north coast of Kenya provides nursery and feeding grounds for pelagic fishes such as sharks, sailfish, marlin and swordfish while at the same time supporting an important artisanal fishery and a semi-industrial bottom trawl prawn fishery

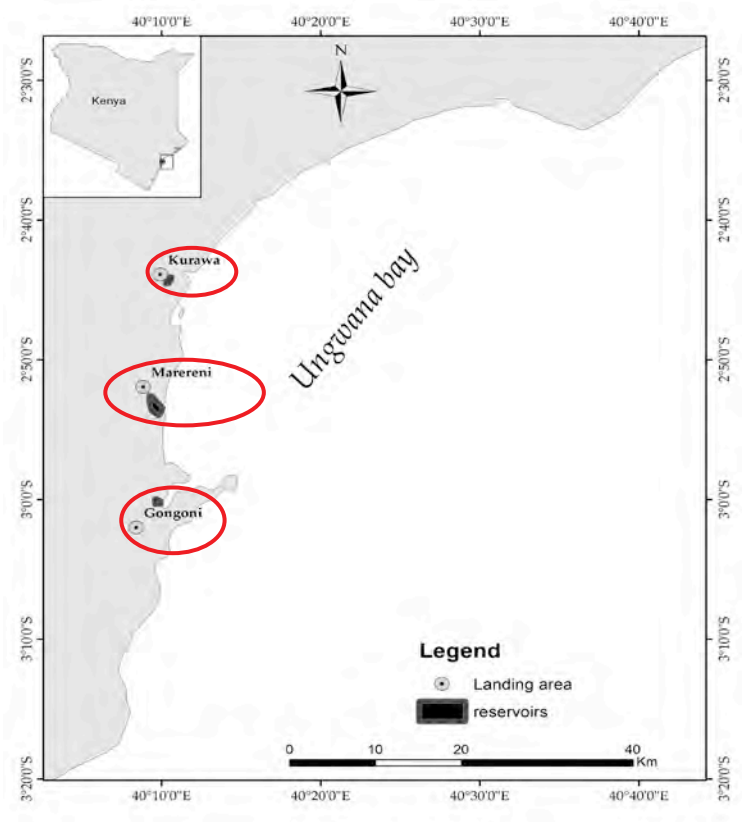

Figure 1. A map showing the Ungwana Bay and the selected solar salt works reservoirs (fish landing sites) on the north coast of Kenya.

(Fig. 1; WWF, 2002; Munga *et al*., 2014). The Ungwana Bay is part of the larger Malindi-Ungwana Bay complex (2°30'- 3°30'S; 40°- 41°E) extending along a shoreline of about 200 km, and has a total trawlable area of about 11 000 km^2 (Fig. 1; Munga *et al*., 2014). Artisanal fishing and prawn trawling activities are concentrated around the Tana and Sabaki river estuaries and shallow offshore banks (Kitheka *et al*., 2005; Kitheka, 2013). Mangrove forests, patchy reefs, islets, sandy shores and tidal flats are the main habitats in the bay. Weather patterns are dominated by large scale pressure systems of the Western Indian Ocean, and the dry NEM season (October to March) and wet SEM season (April to September) (McClanahan, 1988). This study was specifically conducted in selected solar salt works reservoirs along the Gongoni-Kurawa stretch of the Ungwana Bay. The area lies in the semi-arid region of coastal Kenya and experiences hot and dry conditions with heavy rains only in some parts further north (Gordon *et al*., 2013).

Data Collection

Catch and effort data were collected for 10 months between January 2015 and February 2016 at the three selected reservoirs of Gongoni, Marereni, and Kurawa (Fig. 1). These selected reservoirs represent major fishing grounds for the artisanal fishers in the area. Field sampling was done for five consecutive days every month exclusively targeting fishers of the salt works water reservoirs. These were night fishers who landed their catch early in the morning and day time fishers who landed their catch in the mid-morning and afternoon. Day time fishers were accompanied to the fishing grounds and data on catches, fishing gear, crew size, and fishing duration were recorded. Night fishers were interviewed after landing catches early in the morning.

Total wet weights of catches landed by each fisher or crew were measured using a digital weighing balance (Ashton Meyers® 7767) to the nearest 50g. For larger catches a representative sub-sample of approximately a quarter of the total catch was taken and then sorted into the different categories of fin fish and prawns. Each category was further sorted to species level before recording the number and weight of each species. For smaller catches of up to 1 kg, the entire catch was sorted, individuals counted and weighed by species. Species identification was done using identification keys adopted from the FAO species catalogues and field guides (Lieske & Myers, 2001; Anam & Mostrada, 2012). Species which could not be identified in the field were preserved in 10% formalin and taken to the laboratory for identification.

Data Analysis

Data on weights of catches from fishers for the entire study period were compared across the three reservoirs by season and taxa (fin fish and crustaceans). Catch rate expressed as kg.fisher.$^{-1}$hr^{-1} was calculated as the total weight of catches divided by the total number of fishers sampled, then divided by the active fishing time (hr), and fishing duration, taken as the time when a fisher started fishing until the time the catch was landed (Munga *et al*., 2014). Data were tested for homoscedasticity of variances using the Levene's test (Levene, 1960) prior to statistical analysis, and assumptions for the parametric ANOVA test accepted at $p > 0.05$. Data that did not meet the ANOVA test assumptions were appropriately transformed. The differences in catch rates across reservoirs and between seasons were analyzed using 2-way ANOVA. A post hoc pair-wise comparison using the Tukey HSD test was used to confirm whether differences indeed existed between variables (Tukey, 1977). These tests were conducted using STATISTICA v7® statistical software.

Data on catch by species was first standardized as relative percent contribution prior to analysis, for prawn seines that were recorded in all the three reservoirs, and for prawn seines and traps that were both recorded only in Kurawa reservoir. The multivariate non-Metric Multidimensional Scaling (nMDS) technique was then used to visualize catch composition with season combination for the prawn seines across all the reservoirs. The same technique was used for Kurawa reservoir to visualize composition of prawn seine and trap catches with season combination. The 1-way Analysis of Similarity (ANOSIM) test was used to statistically determine if catch compositions were significantly different. Further, 1-way SIMPER analysis was used to identify which species contributed to the dissimilarity. All these tests were conducted using PRIMER v.6 statistical software (Clark & Warwick, 2001).

The number of individuals by species was used to determine the relative abundance (%). The relative abundance was calculated as:

$$\text{Relative Abundance (\%)} = \frac{\text{Number of individuals per species per site}}{\text{Total number of individual of all species per site}} \times 100$$

Species diversity was analyzed using rarefaction curves. The rarefaction technique standardizes non-uniform sampling and sample sizes, hence it is suitable for comparing diversity of data among different sample sizes (Sanders, 1968). The rarefaction

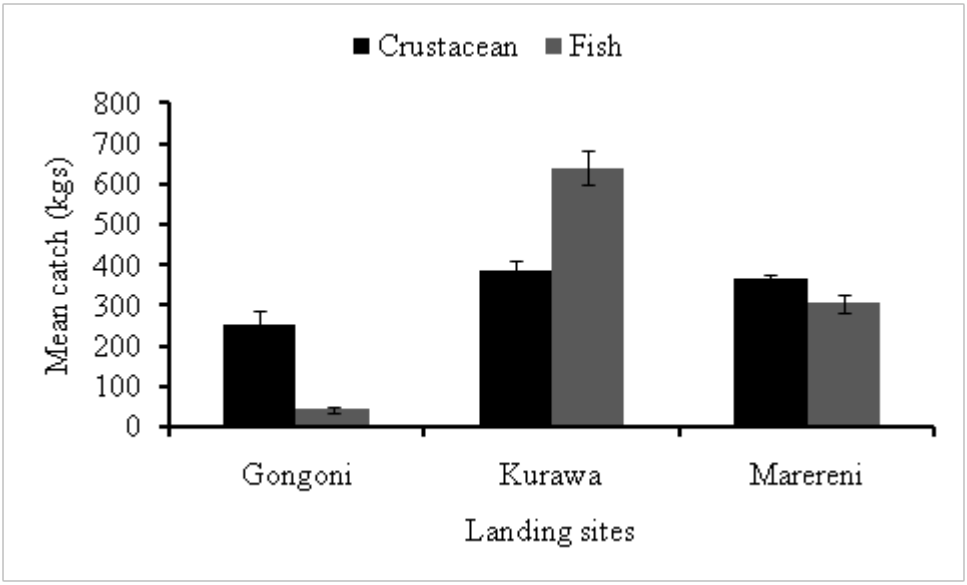

Figure 2. Catch by category (Mean± SE) from the reservoirs of the solar salt works sampled during the study period.

curves analyzed the expected number of species sampled in a given sample size across the reservoirs with season combination.

Results

Total catches sampled from the reservoirs

Two major taxa, finfish and crustaceans (mainly the family Penaeidae) made up the composition of the reservoir catches sampled from both prawn seines and traps. An overall total catch of 4 022.04 kg was recorded during the entire study period with higher catches of prawns (2 046.87 kg, 50.9%) than finfish (1 975.17 kg, 49.1%). The highest total catch was recorded for the northernmost Kurawa reservoir (2 050.6 kg) followed by Marereni (1 338.4kg) and the southmost Gongoni reservoir (633.13 kg). Based on catch category, more crustaceans were recorded in Gongoni and Marereni while more finfish were recorded in Kurawa (Fig. 2). Results of 2-way ANOVA indicated a significant difference in total weight of catches across the reservoirs and between seasons (df = 2; f = 12.033; p = 0.000 and df = 1; f = 13.045; p = 0.001, respectively).

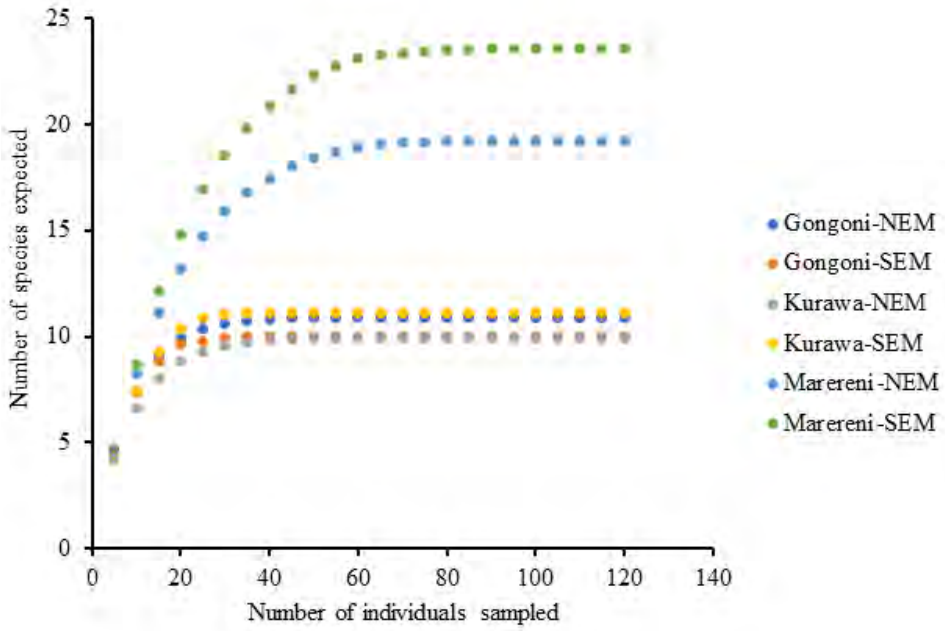

Figure 3. Rarefaction curves indicating the expected number of species caught with increase in sample size by site with season combination for the prawn seine net.

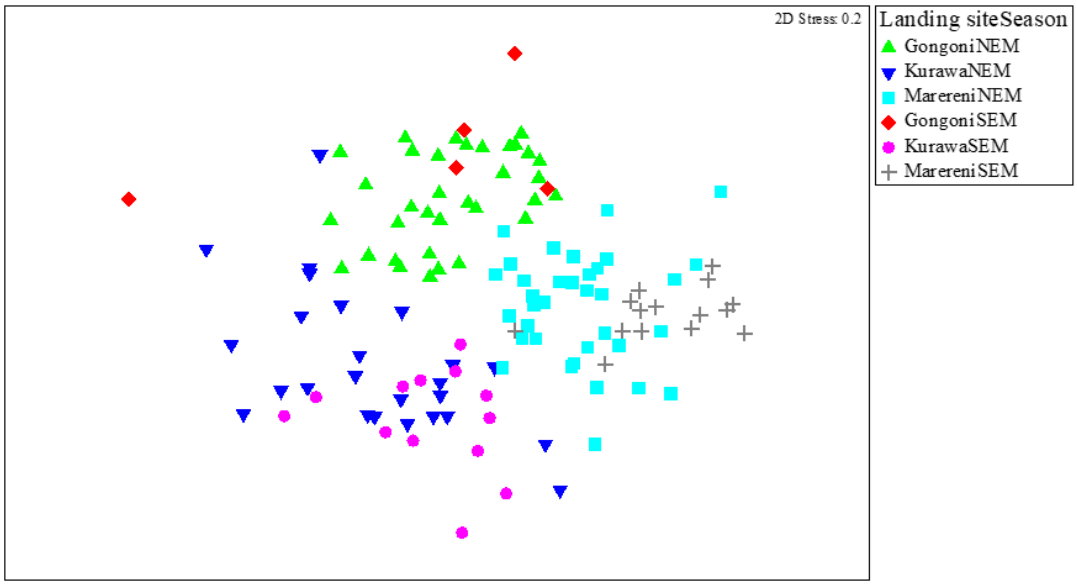

Figure 4. Non Metric MDS showing distinct separation of catches from standardized data by reservoir with season combination in Ungwana Bay, Kenya.

However, the same test indicated no significant difference in catches across reservoirs with season interaction (df = 2; f = 0.468; p = 0.626).

Species diversity of catches and relative abundance

A total of 58 species belonging to 38 families were sampled. These constituted 9 species in 3 families of crustaceans and 49 species of finfish in 35 families. Among the crustaceans, the family Penaeidae was the most speciose with 6 species, while Carangidae for the finfish had the most species (4). Higher total number of species (54) were recorded during the NEM, as compared to the SEM (48). Spatially, Marereni recorded the highest number of species (29 ± 2), followed by Kurawa (17 ± 2), while Gongoni had the lowest number of species (15 ± 1). Further analysis using rarefaction curves confirmed highest species diversity for Marereni samples compared to Gongoni and Kurawa, which recorded lowest, but similar, species diversity (Fig. 3). In most cases, higher species diversity was associated with the SEM season across the reservoirs (Fig. 3).

During the NEM season, *Metapeneaus monoceros* was the most abundant prawn species (13.8%) followed

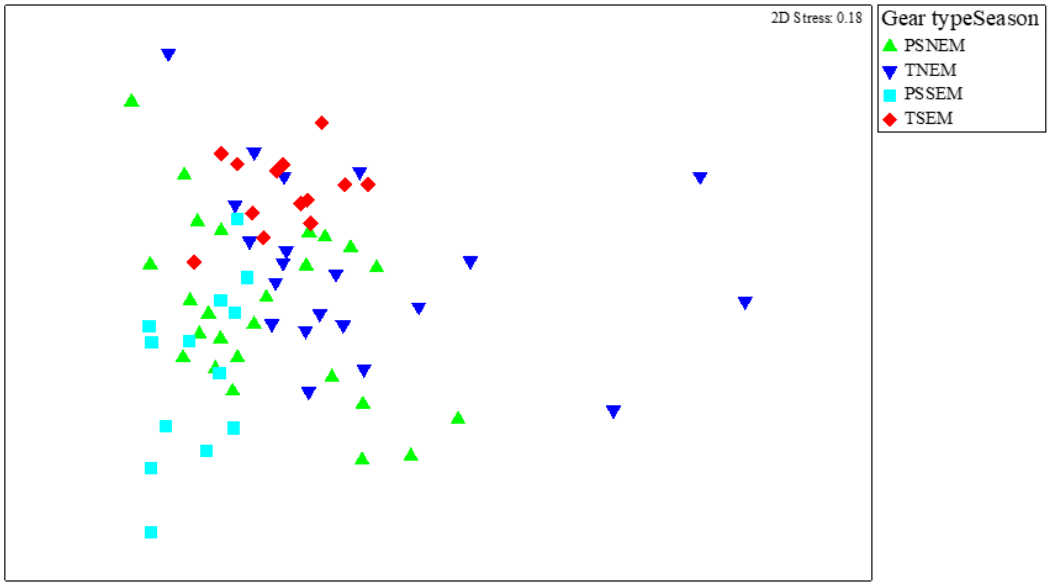

Figure 5. Non Metric MDS showing distinct separation of catches from prawn seines and traps with season combination from standardized data for Kurawa reservoir in Ungwana Bay, Kenya.

Table 1. Species composition and relative abundance (%) by reservoir and season (NEM = Northeast Monsoon; SEM = Southeast Monsoon; bold numbers = most abundant; - = not recorded).

Family	Species	Gongoni		Kurawa		Marereni	
		NEM	SEM	NEM	SEM	NEM	SEM
Penaeidae	*Fenneropenaeus indicus*	**12.9**	**11.4**	**13.9**	**15.5**	8.3	6.4
	Metapenaeus monoceros	**13.8**	**11.4**	12.2	10.7	8.7	**6.7**
	Metapenaeus stebbingi	7.9	11.4	3.8	7.6	6.1	4.0
	Penaeus japonicus	0.3	-	3.3	1.7	3.9	2.5
	Penaeus monodon	**8.5**	-	**12.3**	10.7	6.7	**6.9**
	Penaeus semisulcatus	0.9	10.2	-	6.0	-	1.1
Palaemonidae	*Macrobrachium rude*	-	1.1	2.0	6.0	2.8	5.1
	Nematopalaemon tenuipes	-	-	-	-	0.1	0.4
Carangidae	*Carangoides ferdau*	4.9	**10.2**	0.2	0.2	2.2	2.9
	Carangoides malabaricus	-	-	0.1	-	-	-
	Caranx heberi	1.8	3.4	-	0.2	-	-
	Caranxs pecioza	-	-	0.6	-	-	-
Lutjanidae	*Lutjanus bohar*	-	-	-	-	-	0.6
	Lutjanus ehrenbergii	-	1.1	-	-	-	-
	Lutjanus fulviflamma	0.4	-	0.2	-	1.7	3.5
Lethrinidae	*Lethrinus lentjan*	-	-	0.6	-	0.1	-
	Lethrinus mahsena	-	-	0.4	-	0.4	1.0
	Lethrinus nudus	-	-	0.2	-	-	-
Terapontidae	*Terapon jarbua*	1.0	2.3	4.1	2.1	5.7	5.3
	Terapon puta	0.3	-	0.1	0.5	0.1	-
Engraulidae	*Thryssa malabaricus*	-	-	-	-	1.6	-
	Thryssa vitrirostris	2.0	-	-	-	-	-
Haemulidae	*Diagramma pictum*	-	-	-	-	0.1	0.6
	Plectorhinchus gaterinus	-	-	0.7	-	0.7	1.8
	Plectorhinchus gibbosus	-	-	-	-	0.1	-
Clupeidae	*Amblygaster sp.*	-	-	-	-	0.2	-
	Spratellomorpha bianalis	-	-	0.1	-	-	-
Gobiidae	*Glossogobius giuris*	-	-	-	-	1.1	-
	Gobies sp	11.8	**10.2**	6.6	4.8	7.0	6.5
Alpheidae	*Alpheus sp.*	-	-	0.4	-	1.2	1.5
Ambassidae	*Ambassis natalensis*	5.4	6.8	1.0	1.4	4.5	5.2
Anguillidae	*Anguilla anguilla*	-	-	0.1	-	0.3	0.8
Ariidae	*Arius africanus*	-	-	-	-	0.1	0.4
Atherinidae	*Atherinomorus lacunosus*	-	-	1.2	-	0.1	-
Chanidae	*Chanos chanos*	-	1.1	8.2	5.0	3.6	2.4

Chirocentridae	*Chirocentrus nudus*	0.1	-	-	-	0.7	1.0
Belonidae	*Crocodilus crocodilus*	-	-	-	-	-	0.7
Cynoglossidae	*Cynoglossus durbanensis*	-	-	-	-	0.1	0.4
Serranidae	*Epinephelus malabaricus*	-	-	-	-	0.4	1.0
Gerrenidae	*Gerres oyena*	1.5	-	-	3.3	2.7	5.0
Gonodactylidae	*Gonodactylus smithii*	-	-	-	-	0.4	-
Hemiramphidae	*Hemiramphus far*	8.3	4.5	2.2	1.2	5.5	3.2
Sciaenidae	*Johnius dissumieri*	1.0	3.4	-	1.0	-	-
Leiognathidae	*Leiognathus equulus*	0.6	-	0.2	-	1.9	1.9
Scaridae	*Leptroscarus vaigiensis*	-	-	-	-	0.1	0.2
Mugilidae	*Liza macrolepis*	0.1	-	-	3.3	0.3	2.3
Megalopidae	*Megalops saura*	-	-	0.2	-	0.5	0.7
Monodactylidae	*Monodactylus argenteus*	2.0	2.3	0.5	0.2	2.1	4.2
Mugilidae	*Mugil cephalus*	0.9	-	-	-	-	0.5
Cichlidae	*Oreochromis mossambicus*	4.1	4.5	**18.2**	**14.0**	6.0	1.3
Sciaenidae	*Otolithes ruber*	-	1.1	-	-	-	-
Mullidae	*Parupeneus indicus*	-	-	-	-	-	0.1
Pristigasteridae	*Pellona ditchela*	1.6	-	-	0.2	0.8	1.1
Ephippidae	*Platax orbicularis*	-	-	-	-	0.2	0.1
Portunidae	*Scylla serrata*	3.6	3.4	2.7	2.4	3.3	4.4
Siganidae	*Siganus sutor*	0.1	-	-	-	0.3	-
Sillaginidae	*Sillago sihama*	0.5	-	2.3	1.9	2.0	3.5
Sphyraenidae	*Sphyraena barracuda*	0.4	-	0.1	-	1.8	2.7

by *Fenneropeneaus indicus* and *Penaeus monodon* (12.9% and 8.5%, respectively) for Gongoni. The finfish species *Oreochromis mossambicus* was the most abundant (18.2%) for Kurawa, followed by the prawns *F. indicus* (13.9%) and *P. monodon* (12.3%). *M. monoceros* was also the most abundant species (8.7%) for Marereni followed by *F. indicus* (8.3%) (Table 1). During the SEM season, *F. indicus*, *M. monoceros* and *M. stebbingi* were the most abundant species, each at 11.4% for Gongoni, followed by *P. semisulcatus* (10.2%), and the finfish *Gobies* sp. and *Carangoides ferdau* at 10.2% each. For Kurawa, *F. indicus* was the most abundant (15.5%) followed by *O. mossambicus* (14.0%) and *M. monoceros* and *P. monodon* at 10.7% each. *P. monodon* was the most abundant (6.9%) followed by *M. monoceros* (6.7%) and *F. indicus* (6.4%) for Marereni.

The non-Metric Multidimensional Scaling (nMDS) plots showed distinct composition of prawn seine catches across the reservoirs, and to some extent distinct between the seasons (Fig. 4). Results of 1-way ANOSIM indicated a significant difference in the composition of samples with season combination ($R = 0.675$; $p = 0.001$). Pair-wise comparison tests confirmed these differences ($p < 0.05$ in all cases). The average seasonal dissimilarities within reservoirs were: 49.1% for Gongoni, 41.0% for Marereni, and 47.3% for Kurawa. Higher average dissimilarities across reservoirs in the NEM season ranged between 48.9% to 53.6%, and between 57.6% and 63.0% for the SEM season. Much higher average dissimilarities across reservoirs and between seasons ranged between 52.3% and 63.8%. One-way SIMPER analysis indicated the differences across reservoirs was attributed to more abundant *O. mossambicus* for Kurawa reservoir than for Gongoni and Marereni reservoirs. The seasonal difference in composition for Gongoni was attributed to more abundant *M. stebbingi* and *P. semisulcatus* in the SEM, and more abundant *P. monodon* in the NEM. For Kurawa, seasonal difference was attributed to more abundant *M. stebbingi* and *P. semisulcatus* in the SEM than in the NEM. In Marereni, more abundant *O. mossambicus* and *P. semisulcatus* in the

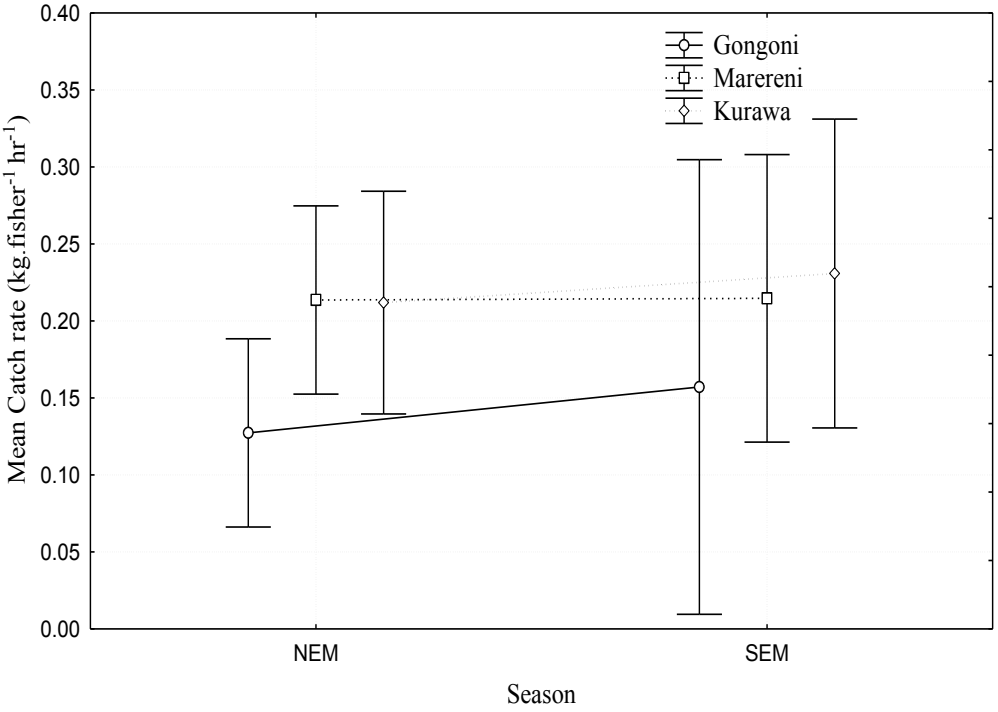

Figure 6. Seasonal mean catch rates (kg.fisher-1hr-1± SE) by reservoir recorded during the study period.

NEM than the SEM attributed to the seasonal difference in species composition.

The nMDS for catch composition from prawn seines and traps for Kurawa reservoir showed distinct composition between gear type and to some extent with season (Fig. 5). Results of 1-way ANOSIM indicated a significant difference in the composition of catches between the gear types with season combination (R = 0.221; p = 0.001). Pair-wise comparison tests confirmed all catch compositions between gear types with season combination differed significantly ($p < 0.05$), but no significant seasonal difference in catch composition of trap samples within the reservoir was apparent ($p > 0.05$). The dissimilarity between prawn seine samples and trap samples in the NEM was 49.30%. This dissimilarity was attributed to more abundant *O. mossambicus* in trap samples than prawn seine samples. The dissimilarity between the two gears during SEM was 49.25%, mainly attributed to more abundant individuals of *P. monodon, Macrobrachium rude* and *M. stebbingi* during this season.

Catch rates

The catch rates were calculated and compared across reservoirs and between seasons. In all the reservoirs, higher catch rates were recorded during the SEM season (Fig. 6). Overall, the highest catch rate was recorded for Kurawa during the SEM season (0.23 ± 0.053 kg.fisher.$^{-1}$hr^{-1}) and the lowest was recorded for Gongoni in the NEM season (0.12 ± 0.007 kg.fisher.$^{-1}$hr^{-1}; Fig. 6). Results of 2-way ANOVA indicated no significant difference in catch rate between seasons and also across the reservoirs (df = 1; f = 0.182; p = 0.670 and df = 2; f = 1.382; p = 0.255, respectively). The same test showed no significant difference in catch rate with season and reservoir interaction (df = 2; f = 0.004; p = 0.952).

Discussion

Higher prawn catches from the reservoirs were associated with the dry NEM season. This is contrary to the situation in Ungwana Bay and all the East African prawn fisheries, where higher catches are associated with the wet SEM season (Teikwa & Mgaya, 2003; Mwatha, 2005; Munga *et al*., 2012). Ndoro *et al*. (2014) associated higher prawn catches during the SEM season in Ungwana Bay with the increase in productivity as a result of increased river discharge. During the rainy season, juvenile prawns migrate from the brackish water estuaries to more saline water offshore to complete their life cycle (Staples & Vance, 1986). This seasonal migration between inshore and offshore waters influences the availability of prawns to fishers and could be a possible reason for their low catches from the reservoirs during the SEM season. In addition, low prawn catches during the SEM season in this study may also be attributed to low sampling frequency during the rainy season. Further, it was

observed that in some instances, the salt works shifted from a daily regime of pumping water to the reservoirs, to a weekly basis, as a strategy to counter the effects of precipitation on the salt pans, which together with low evaporation, resulted in low salt production. This clearly limited the supply of prawns and fin fish into the reservoirs and may have contributed to the low catches recorded during the SEM season.

The non-Metric Multidimensional Scaling (nMDS) plots clearly indicated that the catch compositions were distinct across the reservoirs with season combination. As much as the reservoirs experienced similar conditions in terms of the salt works operations, their differences in proximity to the inshore fishery and to the point of river discharge might have an effect on their environmental parameters, which in turn could influence the composition and abundance of the available species. Mangi *et al*. (2007) noted that variations in catches and compositions across sites in the artisanal fishery could be as a result of factors such as differences in habitat structure, time of fishing, duration and gear type. Differences in catch composition due to gear type has been well captured in Kurawa catches where both prawn seines and traps were encountered. Other authors further suggested that the variations in catch composition give an insight to the selective nature of a gear and how it is operated, and also the available fish communities in a given area (Fauconnet *et al*., 2015). Dall *et al*. (1990) observed that habitat choice, especially for penaeid prawns, is species dependent, thus some species were more abundant in some habitats than others.

A relatively high diversity of species exist in the reservoirs with a total of 58 species recorded in this study. However, despite the high diversity, only few species dominate the catches from the reservoirs. Similar findings have also been reported in other tropical coastal artisanal fisheries (Gell & Whitington, 2002; Mbaru, 2013). The diversity of species recorded from the reservoirs were similar to those reported in the adjacent inshore fishery in the Bay, suggesting that there is a link between the reservoirs and inshore fishing grounds. For example, *M. monoceros*, *F. indicus,* and *P. monodon* reported in this study, have also been reported in other studies in the Bay (Munga *et al*., 2013; Ndoro *et al*., 2014; KMFRI, 2015). Among the penaeid prawns recorded in the present study, *M. monoceros* and *F. indicus* dominated at the landing sites during the NEM and SEM seasons. Studies done elsewhere in the Western Indian Ocean (WIO) region, for example by Subramaniam, (1980) in Tanzania, Gammelsød, (1992) on Sofala Bank in Mozambique, Munga *et al*., (2013) and Ndoro *et al*., (2014) in Ungwana Bay, recorded highest abundances of *F. indicus* followed by *M. monoceros*. Macia (2004), Forbes & Demetriades (2005), and de Freitas (2011), suggested that juveniles of *M. monoceros* and *F. indicus* prefer turbid waters to escape from predators. These observations are consistent with Subramaniam, (1980) who reported that *F. indicus* prefer muddy and mangrove habitats. Therefore, the location of the reservoirs adjacent to mangrove creeks and their proximity to the mouth of the Sabaki River (Kitheka, 2013) creates an environment which favors high abundances in the reservoirs.

Catch rates varied across the reservoirs but these did not differ significantly between the seasons. Although fishing effort in terms of fishing duration (hrs) was similar to that reported in other studies on artisanal fisheries (Ochiewo, 2004; Hoorweg *et al*., 2008), generally relatively low catch rates were recorded. Consistently, other studies by Mbaru (2013) and KMFRI (2015) in the Ungwana Bay artisanal fishery have reported relatively low catch rates ranging between 0.5 and 1.0 $kg.fisher^{-1}hr^{-1}$ which is close to what is reported in this study. Sobrino *et al*. (2003) associated low catch rates with exploitation of juvenile fishes and prawns. This could be the cause of the low catch rates in this study considering that the taxon, especially the penaeid prawns, caught from the reservoirs were all juveniles. Based on the suggestion by Mbaru *et al*. (2011), catch rate is necessary to determine the Maximum Sustainable Yield (MSY) and Potential Yield of a fishery. This is in addition to the use of biological indices such as size and condition factor of the species. Therefore, the low catch rates in this study could suggest that the reservoirs may not be able to sustain the present artisanal fishery. However, it is noted that this study was carried out over a relatively short period of time and longer term studies will be required to ascertain this.

In conclusion, the dynamics of fishing activities and fisheries production in the reservoirs was influenced mostly by factors such as the location of reservoirs, the effect of seasons to some extent, as well as gear type, as shown for Kurawa reservoir. It is also evident that the salt works reservoirs have some potential for supporting artisanal fishing in the area with significant catches landed throughout the year. It is however, recommended that longer term studies be conducted to generate more information necessary for formulation of guidelines for the sustainable management of the reservoir fisheries in the area.

Acknowledgements

We wish to express our sincere gratitude to the Western Indian Ocean Marine Science Association (WIOMSA) through the provision of Marine Research Grant (MARG1) and the Kenya Coastal Development Project (KCDP) for providing additional funding for this study. We thank the Kenya Marine and Fisheries Research Institute (KMFRI) staff, particularly Mr. Kennedy Oduor, Mr. Sammy Kadhengi, Ms. Winnieann Ng'endo, and Mr. Paul Kipkemoi who assisted in the field data collection. We also thank the salt work owners, the Beach Management Units officials, fishers and traders for their cooperation and participation at the time of data collection.

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