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Metapenaeus dobsoni (Miers, 1878), an alien Penaeidae in Mozambican coastal waters: confirmation by mtDNA and morphology analyses

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Abstract

An alien shrimp species has been increasingly recorded in Maputo Bay, Mozambique, and its occurrence has been associated with a drastic reduction of a native and economically important Indian white shrimp, *Fenneropenaeus indicus*. Cytochrome c oxidase subunit I sequencing and body morphology analyses were used to identify this alien species. All results revealed its taxonomic identity as *Metapenaeus dobsoni* (Kadal shrimp), a native species from the eastern Indian Ocean, originally not recorded on the Mozambique coast. Maputo Bay is considered an important biodiversity hotspot and there are concerns regarding the presence of this alien species, which could weaken the biodiversity of the Bay. Moreover, the increased contribution of this small-size shrimp within the fishery is of concern because of its potential negative impacts on fisheries and economic stability in the region.

Keywords: Alien species; Molecular identification; COI; Biodiversity; *Metapenaeus dobsoni*

Introduction

Invasive species are generally associated with a number of negative impacts to native biodiversity. These impacts may affect the natural environment, the local economy and even human health (Leão *et al.*, 2011). Invasive species may start competing or become predators of native species (Hill & Lodge, 1999; Leão *et al.*, 2011; Scannella *et al.*, 2017), or even vectors of parasites and other pathogens (Torchin & Mitchell, 2004; Leão *et al.*, 2011). Shrimps and other crustaceans can host viral pathogens that are dangerous for other species inhabiting the same environment. A well-known example of dangerous viral diseases that affect shrimps is the White Spot Syndrome Virus (WSSV) (Hoa *et al.*, 2011; Bateman *et al.*, 2012). In addition, exotic species may hybridize with native species (Firmart *et al.*, 2013) and reduce local biodiversity by eliminating the natives (Dick & Platvoet, 2000). According to Shine *et al.* (2000), alien species are those occurring outside their "natural distribution", because they cannot reach this location by their own means, and some kind of human action is involved in the introduction to the new location. If an alien species becomes established in a new habitat, and is able to reproduce and generate fertile descendants with a high probability of survival, it is then regarded as an alien invasive species (Shine *et al.*, 2000; Ciruna *et al.*, 2004).

The family Penaeidae contains several important commercial species that inhabit shallow coastal waters of tropical and subtropical regions (Dall *et al.*, 1992; Chan, 1998). Nine genera belonging to this family have been identified along the southeast coast of Africa, from the Rovuma River in northern Mozambique to the Kei

River in South Africa. Most of these shrimps inhabit the continental shelf, between 5 and 70 m deep.

In Mozambique, shrimp fishery is historycally known as one of the pillars of economic growth, where *Penaeus monodon* (Giant tiger prawn), *Melicertus latisulcatus* (Western king prawn), *Metapenaeus monoceros* (Speckled shrimp), *Metapenaeus stebbingi* (Peregrine shrimp), *Marsupenaeus japonicus* (Kuruma prawn), *Fenneropenaeus indicus* (Indian white prawn), and *Penaeus semisulcatus* (Green tiger prawn) are the most frequently captured species. Among these, *F. indicus* and *M. monoceros* are the most abundant species supporting commercial fisheries. Since 2007 a new shrimp species has been recorded in Maputo Bay. This species had never been recorded in this area, or along the Mozambican coastal waters. This has created dissatisfaction among the fishing community due to a smaller body size than the native commercial species. In addition, its occurrence might be associated with a significant decrease in the abundance of *F. indicus*.

In this paper, mitochondrial DNA (mtDNA) and body morphology analyses were used to identify the species as *Metapenaeus dobsoni*, a native species from eastern Indian Ocean, and confirm that it is an alien species currently present in Maputo Bay, Mozambique. Simbine (2016) reported the presence of this species on the Mozambique coast for the first time. The present study confirms the occurrence of this species and might provide information that will be useful in its management, and protection and conservation of native species.

Materials and methods

Shrimp specimens were sampled from July 2010 to June 2011 in Maputo Bay, Mozambique (Fig. 1a, 1b). A total of 26 individuals were collected: *5 M. monoceros*, 4 *M. stebbingi*, 5 *F. indicus*, 2 *P. monodon*, 3 *M. japonicus*, and 7 individuals of the alien species.

After collecting the samples, a piece of muscle tissue (approximately 1.5 cm^2) was extracted, avoiding damage to the morphological characteristics of the individual,

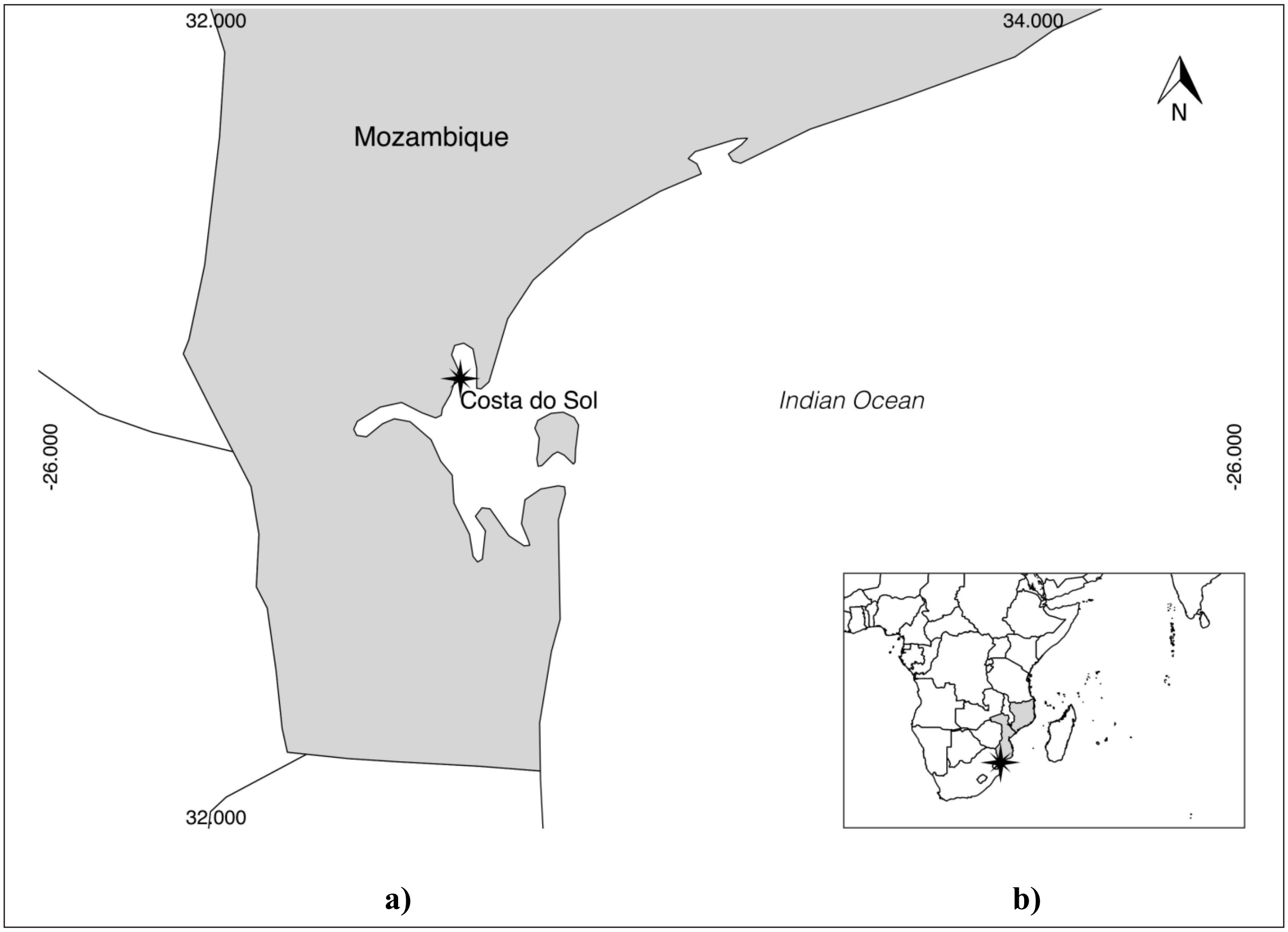

Figure 1. a) Maputo Bay showing the sampling location at 26° 11' 30"S, 32° 45' 30"E, and b) Map showing the location of Mozambique.

and immediately preserved in 95% ethanol, maintained at a temperature of 4°C until DNA extraction.

DNA extraction was carried out according the method used by Sambrook *et al.* (1989). A segment of 598 base pair (bp) of the cytochrome c oxidase subunit I (COI) mitochondrial gene was amplified using COIPenF forward and COIPenR reverse primers for penaeids. PCR was carried out in a final volume of 30 µl, containing 3.0 µl of DNA template (50ng/µl), 3µl of 10X reaction buffer, 1.5µl of 2.5mM $MgCl_2$, 2.4 µl of dNTP mixture containing 2.5mM of each dNTP, 0.9µl of each 10pmol primer (forward and reverse), and 1 U of Taq platinum (Invitrogen). The amplification protocol was carried out in a Veriti TM 96 thermocycler (Applied Biosystems) under the following conditions: 94°C for 5 min, 35 cycles of 94° C for 30 s, 51°C for 55 s and 72°C for 1 min, followed by 72°C for 30 min of final extension. Purified PCR products (Lis, 1980) were sequenced in an automatic sequencer (Korean Macrogen Inc. Service).

Nucleotide sequences were aligned using Clustal W software (Thompson *et al.*, 1994) implemented in the programme Geneious R6 (Kearse *et al.*, 2012). The genetic distance was calculated within and between species using the Mega 5.05 software (Tamura *et al.,* 2004) and Kimura 2-parameter (K2P) model. Sequences of related species were obtained from GenBank, and a genetic distance tree was obtained using the Neighbor-Joining (NJ) method (Tamura *et al.,* 2004) by bootstrapping the data with 1,500 replicates. *Macrobrachium rosenbergii*, of which sequences were obtained from GenBank, was used as an external group. Additionally, a network of haplotypes was built using Network 4.5.1.6. (Bandelt *et al.*, 1999).

Morphological analysis was performed by two groups of taxonomists from different institutions, Universidade do Estado do Rio de Janeiro (UERJ, RJ, Brazil), and Central Institute of Marine Fisheries Research (Kerala, Kochi-India). Morphology analysis (Dall *et al.*, 1992; Rao *et al.*, 2013) used five individuals of

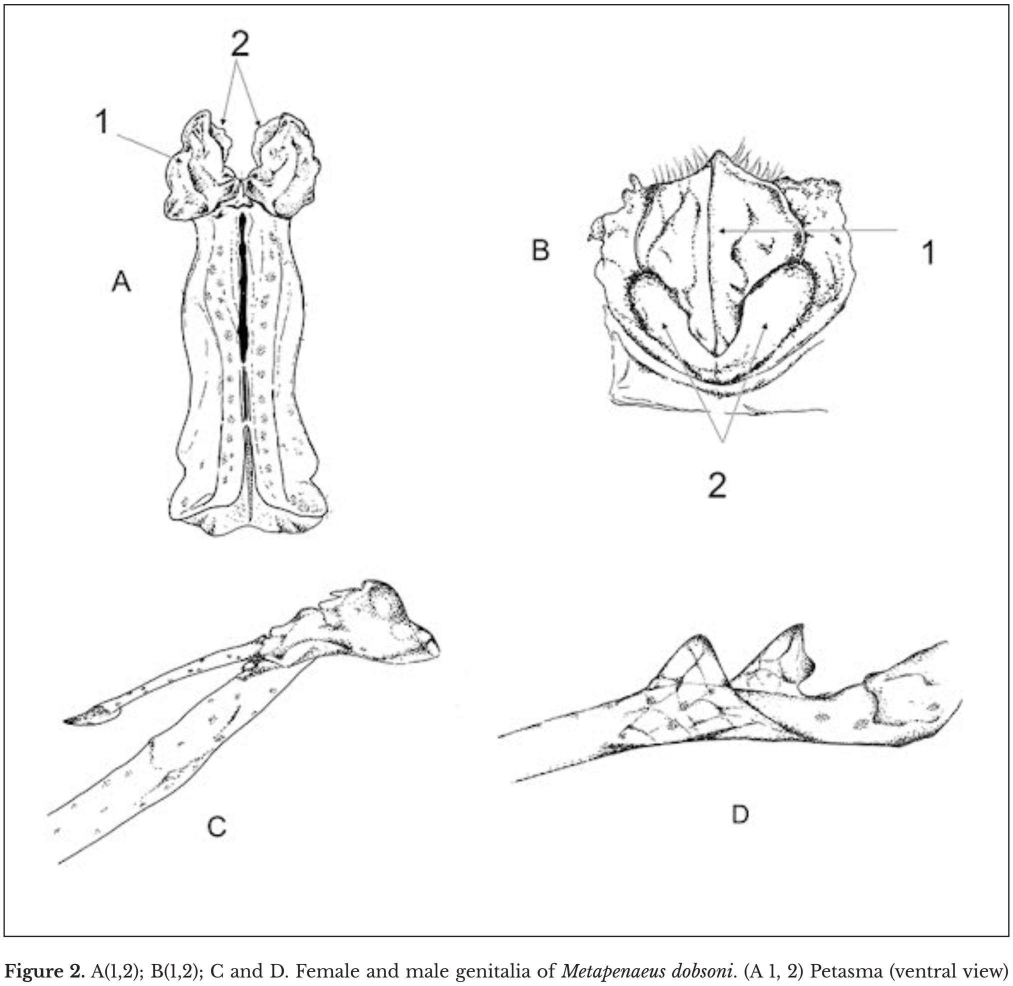

Figure 2. A(1,2); B(1,2); C and D. Female and male genitalia of *Metapenaeus dobsoni*. (A 1, 2) Petasma (ventral view) showing the disto-median and disto-lateral projection. (B 1, 2) Thelycum showing a long groove and two lateral plates. (C, D) Basial spine of the third leg (male). Drawn by Fernando Peron Magrini.

each species, comparing both Mozambican and Indian shrimp groups. Vouchers were deposited in the crustacean collection of Laboratório de Genética Pesqueira e da Conservação (LGPESC, UERJ, RJ, Brazil).

Shrimp fishery records were obtained from Instituto Nacional de Investigação Pesqueira (IIP), Mozambique, which is responsible for scientific fisheries monitoring in the country, especially focusing on shrimps. Monitoring activities include recording the type of fishing gears used (artisanal otter trawl - ARB; beach-seine - ARP; bottom gill-net – EMF; and semi-industrial bottom trawling - SEMI), the size of landed specimens, and landings. The catch data presented in this paper are from Maputo Bay.

Results

Morphological description

Traditional morphological taxonomic analysis concluded that the alien species was *Metapenaeus dobsoni*, an Indo-Pacific species originally distributed along the coasts of India, Sri Lanka, Malaysia, Indonesia, the Philippines and New Guinea (Rao *et al.*, 2013). It is characterized by the presence of a long rostrum armed with 8-9 spines on the dorsal side, with a well-marked double curve, the exopodite absent on the fifth leg of the thorax, the branchio-cardiac groove reaching almost to the middle of the carapace, the pleurobranch on seventh thoracic somite, the telson armed only with spinules, and the absence of robust ischial setae on the pereiopod. Adult males are characterized by basial robust setae of the third pereiopod with 1 or 2 large triangular spines, each disto-median projection of the petasma with a short filament on the ventral surface and another filament on the dorsal surface (Fig. 2 A, C and D). The fifth pereiopod in females is often reduced to a coxa and basis. The thelycum has a long groove dorsally unsheathed in a horseshoe-like process formed by lateral plates (Fig. 2 B).

According to the description of Rao *et al.* (2013), the body colour is transparent with red or greenish specks, the distal part of the therostrum is darker, antennules and antennae are dotted red, pereiopods and pleopods are white to pinkish, the uropods are red, darker distally with external parts of exopods red, and a double row of reddish spots on the telson with a greenish margin.

DNA sequencing

Partial sequences (598 bp) of the COI gene of this species and of the native Mozambican species *F. indicus*, *M. monoceros, M. stebbingi, M. japonicus and P. monodon* were successfully amplified. All sequences were deposited at GenBank (Accession numbers KM508829 - KM508847). Thereafter, the sequences of *M. dobsoni, Metapenaeus brevicornis, M. japonicus, Litopenaeus vannamei, P. monodon, Farfantepenaeus californiensis* and *Fenneropenaeus chinensis*, obtained from GenBank, were compared (Table 1).

The genetic distance tree with well-supported bootstrap values linked the sequences of the exotic species to previous GenBank *M. dobsoni* sequences in a unique branch. In addition, a *Metapenaeus* clade was recovered (Fig. 3), reinforcing the results of the morphological analysis. The haplotype network of *M. dobsoni* showed two distinct groups, one with samples in green from India and the other with the samples in blue from Mozambique (Fig.4).

The sequence variation between species was high. The pairwise COI divergence between *M. dobsoni* and *M. monoceros, M. brevicornis*, and *M. stebbingi* were 22.6, 24.8 and 29.9%, respectively. On the other hand, highest values (43.53% to 48.71 %) were found between *M. dobsoni* and the remaining species that did not belong to the *Metapenaeus genus* (Table 2). In contrast, the level of intraspecific variability was much lower, ranging from 0.0% (*M. monoceros, M. stebbingi and F. californiensis*) to 5.7% (*P. monodon*). *M. dobsoni* showed an intermediate value of 2.8% (Table 3).

Catch records of *F. indicus*, *M. monoceros*, *M. stebbingi, M. japonicus* and *P. monodon* species, as well as of the alien species identified herein as *M. dobsoni*, indicate a steady increase in contribution of this latter species to the total shrimp catch since the year 2007 (Table 4; Fig. 5). A concomitant decrease in catches of the main species, *F. indicus*, has also been observed in all artisanal fishing gears (R^2>0.5), being especially evident for the semi-industrial fleet (R^2 =0.9), which shows a steady trend of fishing effort.

Discussion

The accurate identification of species is an important step to efficiently manage and monitor any population, especially those of great economic value (Ward, 2000; Beerkircher *et al.,* 2009). In addition to morphological taxonomy, molecular markers have successfully been used for species identification (Hebert *et al.*, 2003). Such an approach has increasingly been used for accurate identification of both terrestrial and aquatic alien species (França *et al.*, 2007; Wu *et al.*, 2011; Duggan *et al.*, 2012; Oosterhout *et al.,* 2013; Sabour *et al.,* 2013; Cruscanti *et al*., 2015).

Table 1. Sequence access number and origin of all species obtained in GenBank.

GenBank number	Species	Origin
gi|549445155|	*Metapenaeus dobsoni*	Tamil-Nadu-India
gi|530759033	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759030|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759027|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759039|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759024|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759021|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759018|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759015|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759012|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759009|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759006|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759003|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530759000|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530758997|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530758994|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530758991|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530758988|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|530758985|	*Metapenaeus dobsoni*	Kochi, Kerala- India
gi|549445155|	*Metapenaeus brevicornis*	Tamil Nadu- India
gi|549445154|	*Metapenaeus brevicornis*	Tamil Nadu- India
gi|7374113|	*Penaeus monodon*	Tokyo-Japan
gi|7243610|	*Penaeus monodon*	Australia
gi|63003723|	*Marsupenaeus japonicus*	Tokyo-Japan
gi:66276044|	*Marsupenaeus japonicus*	Tokyo-japan
gi|150375635|	*Litopenaeus vannamei*	Mexico
gi|109692170|	*Litopenaeus vannamei*	China
gi|148532179|	*Litopenaeus vannamei*	Mexico
gi|153125267|	*Fenneropenaeus chinensis*	China
gi|110287619|	*Fenneropenaeus chinensis*	China
gi|282167291|	*Macrobrachium rosenbergii*	China

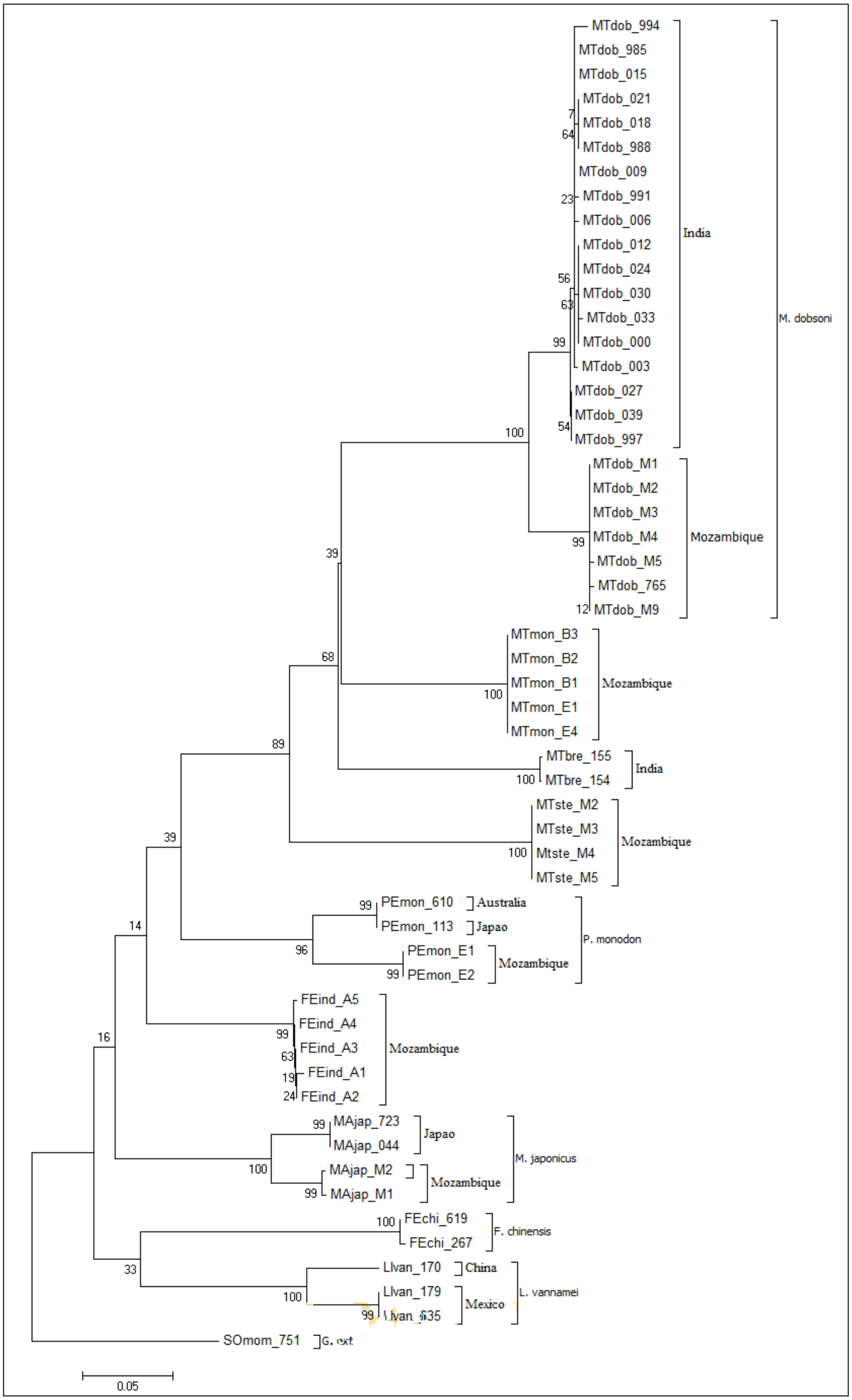

Figure 3. COI gene genetic distance tree. *Metapenaeus dobsoni* (MTdob), *Metapenaeus brevicornis* (MTbre), *Metapenaeus stebbingi* (MTste), *Metapenaeus monoceros* (MTmon), *Penaeus monodon* (PEmon), *Marsupenaeus japonicus* (MAjap), *Litopenaeus vannamei* (LIvan), *Fenneropenaeus chinensis* (FEchi), *Fenneropenaeus indicus (FEind),* and the external group *Macrobrachium rosenbergii* (SOmom).

The combination of morphology and molecular mtDNA COI analyses clearly showed that *Metapenaeus dobsoni* (Miers, 1878) is the alien species currently fished along the Mozambican coastal waters. This conclusion is grounded by the genetic distance analyses. Low genetic distance values found between *M. dobsoni* and the unknown alien species suggest that they are the same species (Table 2). This finding supports the body morphological analysis, which identified the alien species as *M. dobsoni*.

The distance genetic tree recovered two clades in the *M. dobsoni* group, suggesting a genetic population structuring within this shrimp. In this clade, a branch joined individuals from India (sequences from GenBank), while the other branch joined the studied individuals from Mozambique, suggesting that the alien individuals herein detected in Mozambique have probably derived from another area (not India) of *M. dobsoni* natural distribution. The haplotype network showed a similar result, separately grouping all samples from India (green) and from Mozambique (blue).

A recent study of exotic crustaceans inhabiting the Turkish coast indicated that *M. japonicus* has become established, replacing a native species of economic importance, *Melicertus kerathurus* (Ates *et al.,* 2013), whilst *Erugosquilla massavensis* has replaced the native *Squilla mantis* (Özcan *et al.*, 2008). Turkish waters and Mediterranean waters in general, seem to have been invaded by crustaceans through the Suez Canal resulting in settlement of Indo-Pacific migrants (Rodriguez & Suarez, 2001). However, fish and shellfish farms are abundant in lagoons and bays, possibly provided a source of exotic species. The status of invasive species in Turkey was recently assessed and presented a wide range of crustaceans, many of them of economic importance (Kapiris *et al.*, 2012; Scannella *et al.*, 2017).

In Africa, several cases of invasive species have been reported. For instance, the presence of the Japanese seaweed, *Sargassum muticum*, has recently been reported in Morocco (Sabour *et al.,* 2013). A total of 104 introduced or unknown originally alien species are listed in the Western Indian Ocean (ASCLME/SWIOFP, 2012a). Some of these species have already

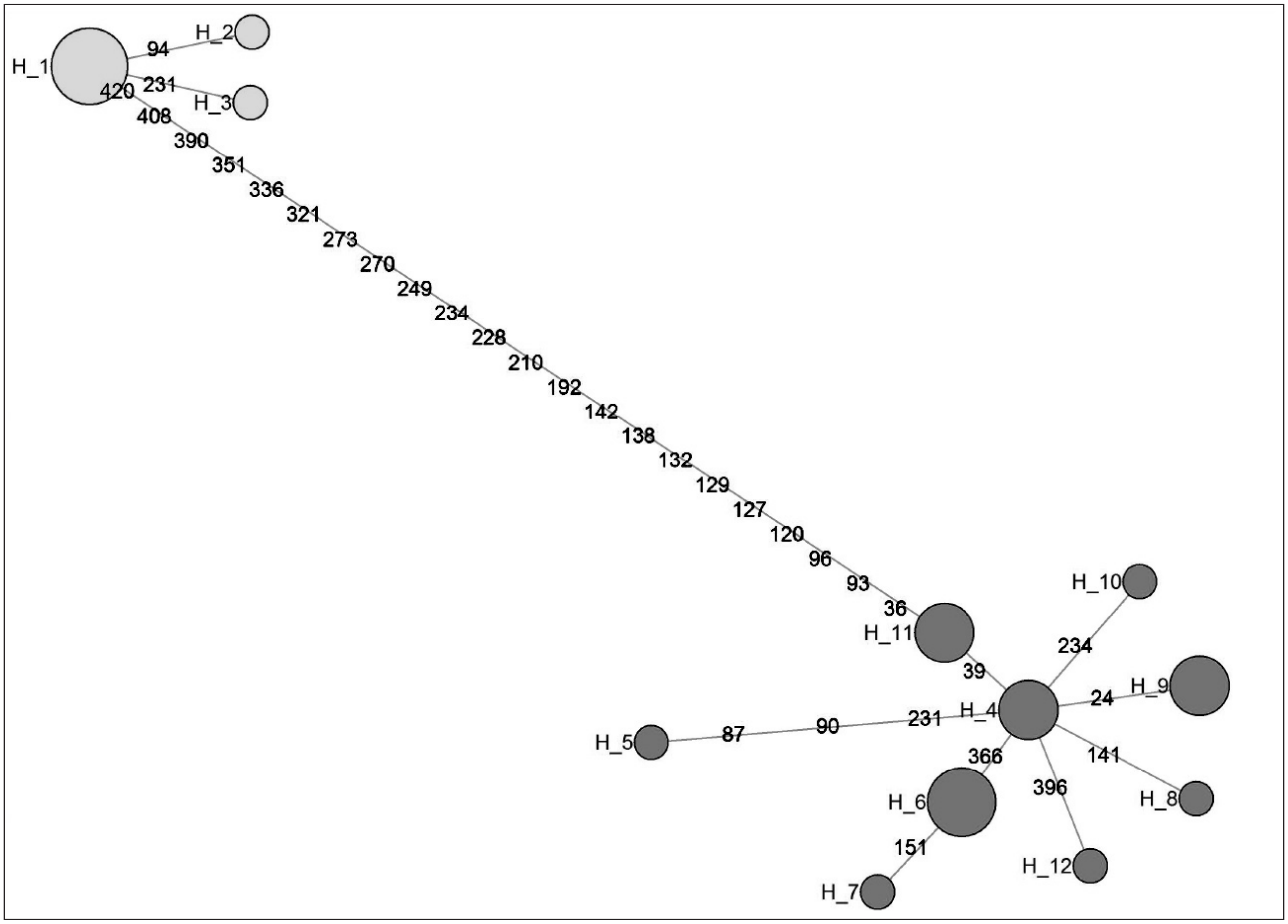

Figure 4. Haplotypes network of *M. dobsoni* showing two distinct groups, Mozambique (blue) and India (green).

been recognized as invasive species. It is therefore imperative that all the species that are on this list are considered to be potentially harmful or disturbing for biodiversity and natural ecosystems (ASCLME/SWIOFP, 2012a).

Several introduced species have been reported in Mozambique in both terrestrial and aquatic ecosystems, reducing biodiversity through hybridization, or even resulting in the extinction of native species (ASCLME/SWIOFP, 2012b). Some alien species such as *Euchornia crassipes*, *Pistia stratiotes*, *Salvinia molesta*, *Azolla filiculoides*, *Myriophyllom aquaticum* and *Lantana camara* are currently widely distributed throughout the country and have caused major negative impacts (MICOA, 2007). Corallivorous crown-of-thorns (*Acanthaster planci*) starfish has also been found on the Mozambican coast, and during 1995-1996 this species had a devastating effect on the coral reefs of Bazaruto Island (80%), and Inhambane (95% - 98%) (ASCLME/SWIOFP, 2012b). Although the data from the present study shows a large decline in the quantities of *F. indicus*, it is still not possible to conclude that *M. dobsoni* is an invasive species.

The present study identified an increase in the occurrence of *M. dobsoni* in fishery catches in Maputo Bay, probably competing with native species. If *M. dobsoni* became an invasive species it would cause great loss to local biodiversity. In addition, considering its smaller

Table 2. Genetic distance matrix between species for the COI gene. Standard errors are shown in the upper diagonal, and values of genetic distance between species in the lower diagonal.

Species	Distance									
M. dobsoni		0,3016	0,2441	0,2448	0,3430	0,1838	0,2132	0,2356	0,1775	0,3987
L. vannamei	0,4352		0,2061	0,2307	0,2101	0,2934	0,2333	0,1798	0,2737	0,3329
P. monodon	0,3375	0,2876		0,2211	0,1623	0,2637	0,2211	0,1679	0,2161	0,3799
M. japonicus	0,3671	0,3095	0,2885		0,2288	0,2867	0,2783	0,1695	0,2697	0,3543
F. chininses	0,4871	0,2805	0,2196	0,3049		0,2469	0,2042	0,1287	0,2151	0,3573
M. brevicornis	0,2484	0,4032	0,3704	0,4008	0,3085		0,1959	0,2284	0,1462	0,3095
M. stebbingi	0,2988	0,3233	0,3170	0,3952	0,2809	0,2528		0,2197	0,1867	0,4724
F. indicus	0,3249	0,2646	0,2188	0,2323	0,1919	0,3034	0,3178		0,2010	0,3113
M. monoceros	0,2263	0,3926	0,3056	0,3809	0,3050	0,2048	0,2548	0,2931		0,3097

Table 3. Kimura two-parameter average genetic distance within species for the COI gene.

Species	Distance
M. dobsoni	0,028
F. chinensis	0,002
L. vannamei	0,053
P. monodon	0,057
M. japonicus	0,042
M. brevicornis	0,002
F. californiensis	0
M. stebbingi	0
F. indicus	0,002
M. monoceros	0

Table 4. Fisheries landings in metric tons of *F. indicus, M. monoceros, M. stebbingi, M. dobsoni* and *M. japonicus* in Maputo Bay during the period from 2007 to 2016.

Fishing gear	Period	*F. indicus*	*M. monoceros*	*M. japonicus*	*P. monodon*	*M. stebbingi*	*M. dobsoni*
ARB	2007	79,0	5,1	0,1	3,6	0,1	0,0
	2008	94,6	1,7	2,7	0,0	0,0	0,0
	2009	76,7	13,8	0,3	4,5	1,2	3,5
	2010	83,5	13,6	0,0	2,8	0,0	0,0
	2011	91,9	1,5	0,0	1,8	0,0	4,7
	2012	78,4	0,0	11,8	2,0	0,0	0,0
	2013	66,0	15,0	0,0	1,0	1,0	2,0
	2014	40,0	39,0		4,0	3,0	6,0
	2015	38,0	40,0	0,0	5,0	3,0	6,0
	2016	61,0	34,0	0,0	3,0	1,0	1,0
ARP	2007	48,4	7,6	9,3	16,9	0,5	0,0
	2008	68,2	3,7	3,7	9,7	1,1	0,0
	2009	58,6	6,7	2,3	14,5	0,8	17,0
	2010	38,8	7,2	1,6	15,0	30,4	6,9
	2011	60,2	14,2	1,3	10,7	0,6	13,0
	2012	31,4	1,2	15,1	29,4	13,2	0,0
	2013	41,0	16,0	4,0	16,0	2,0	1,0
	2014	41,4	1,2	0,1	29,5	0,1	0,7
	2015	41,0	1,0	0,0	30,0	0,0	1,0
	2016	32,0	3,0	9,0	7,0	1,0	0,0
EMF	2007	94,6	0,0	0,0	5,4	0,0	0,0
	2008	94,8	2,1	0,0	0,9	0,4	0,0
	2009	92,3	4,2	0,0	1,1	0,2	2,0
	2010	85,3	1,3	0,0	10,7	0,1	2,7
	2011	90,3	3,0	0,1	2,7	0,3	0,8
	2012	91,6	2,2	0,0	8,4	0,2	0,0
	2013	92,0	3,0	1,0	2,0	0,0	0,0
	2014	86,0	4,0	2,0	4,0	0,0	0,0
	2015	85,0	4,0	2,0	4,0	0,0	0,0
	2016	87,0	3,0	0,0	3,0	0,0	0,0
SEMI	2007	22,5	28,2	2,3	3,1	9,6	20,8
	2008	21,9	4,4	4,6	5,1	8,1	41,6
	2009	18,0	12,0	1,0	1,0	6,0	54,0
	2010	53,0	20,0	0,0	1,0	2,0	21,0
	2011	43,5	21,0	0,0	0,5	2,9	30,1
	2012	34,0	22,0	0,0	0,0	3,8	39,2
	2013	21,0	6,9	0,1	1,3	4,9	59,4
	2014	14,9	13,2	0,0	0,6	1,0	66,6
	2015	13,2	13,8	0,0	1,2	5,1	57,6
	2016	14,2	17,5	0,1	1,2	6,1	51,3

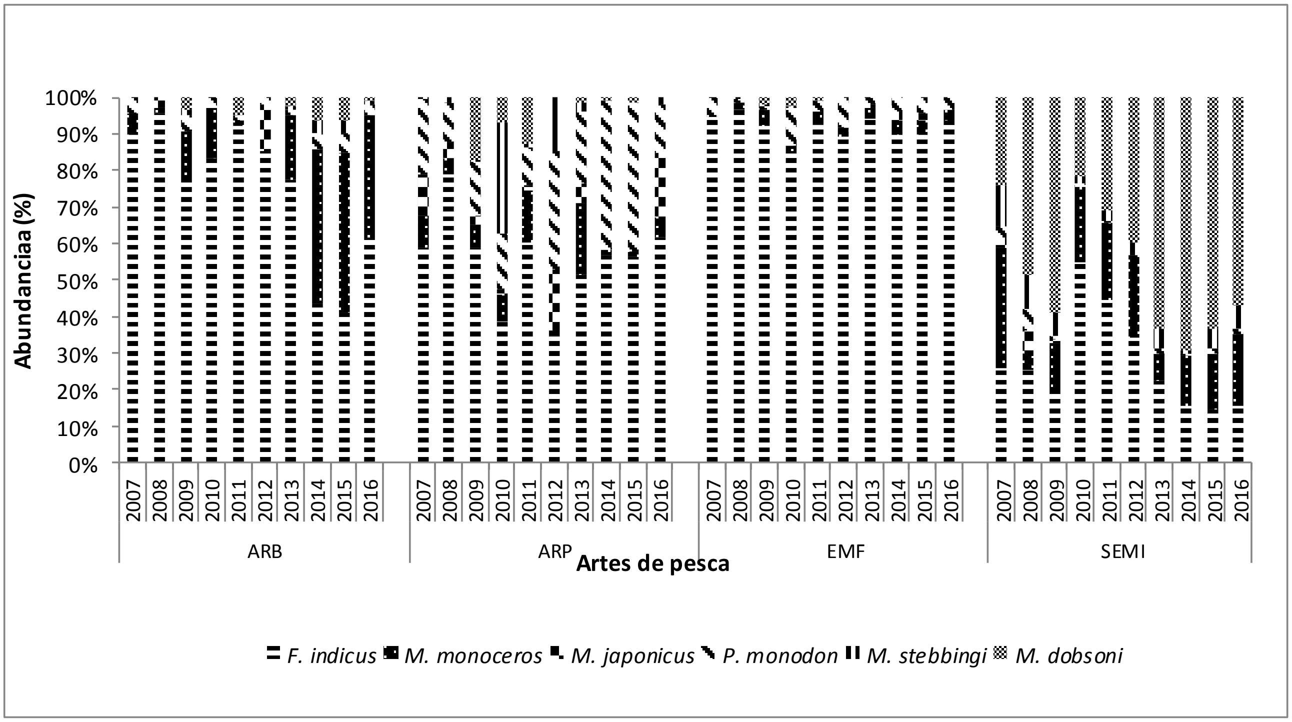

Figure 5. Shrimp landings of Maputo Bay expressed as proportion of *F. indicus*, *M. monoceros*, *M. stebbingi, M. japonicus, Penaeus monodon* and *M. dobsoni* for the years 2007 to 2016.

body size and its reduced economic value, it could result in drastic consequences for the local economy. The current status of *M. dobsoni* is of concern mainly because it may occupy similar ecological niches as native species (Rao *et al*., 2013) that are of vital importance to the economy of the country. An alien species that becomes established in a particular locality alters native biological diversity. Initially, the presence of these species may increase the local number of species, but over time it will reduce (in number and relative abundance) local biodiversity, particularly if native species are not numerous or are replaced in their natural habitat (Shine *et al*., 2000).

In addition to the identification of the alien shrimp species, COI sequences of all penaeid shrimp occurring on the Mozambique coast are reported for the first time in this paper, enlarging the molecular knowledge of family Penaeidae populations. Similar to that observed for the *M. dobsoni* group, the distance genetic tree also revealed population structuring in *M. japonicus* and *P. monodon*, or even recent divergence of cryptic species, which could be resolved in further population studies. In both these species, the population naturally occurring on the Mozambique coast appeared in exclusive clades (African clade) compared with individuals from other areas (Japan for *M. japonicus*, and Australia for *P. monodon*), suggesting that the Mozambique coast maintains an important portion of the overall genetic variation of these shrimp. The potential negative effects that *M. dobsoni* might bring to Mozambique are quite predictable, ranging from a loss of biodiversity to economic losses. Where fishery activities involve this species, it appears that it is also accompanied by an almost total absence of the native white shrimp *F. indicus*, particularly in semi industrial fishing gear. The present study was able to confirm the identity of this alien species and provides a warning of the potential negative impacts for the local biodiversity and economy.

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References

ASCLME/SWIOFP (2012a) Transboundary Diagnostic Analysis of the Large Marine Ecosystems of the western Indian Ocean. Volume 1: Baseline. South Africa. 101 pp

ASCLME/SWIOFP (2012b) Transboundary Diagnostic Analysis of the Large Marine Ecosystems ot the western Indian Ocean. Volume 2: Diagnostic Analysis. South Africa. 282 pp

Ates A, Katagan T, Sezgin M (2013) Exotic crustaceans of the Turkish coast. Arthropods 2: 20-25

Bandelt HJ, Forster P, Rohl A (1999) Median-Joining networks for inferring intraspecific phylogenies. Molecular Biology and Evolution 16: 37-48

Bateman KS, Tew I, French C, Hicks RJ, Martin P, Munro J, Stentiford GD (2012) Susceptibility to infection and pathogenicity of White Spot Disease (WSD) in non-model crustacean taxa from temperate regions. Journal of Invertebrate Pathology 110 (2): 261-266. https://doi.org/10.1016/j.jip.2012.03.022

Beerkircher L, Arocha F, Barse A, Prince E, Restrepo V, Serafy J, Shivji M (2009) Effects of species misidentification on population assessment of overfished white marlin *Tetrapturus albidus* and roundscale spearfish *T. georgii*. Endangered Species Research 9: 81-89

Chan TY (1998) Shrimps and prawns. In: Carpenter KE, Niem VH (eds) The living marine resources of the western central pacific. FAO, Rome, pp 687-1396

Ciruna K, Meyerson L, Gutierrez A (2004) The ecological and socio-economic impacts of invasive alien species in inland water ecosystems. Report to the Convention on Biological Diversity on behalf of the Global Invasive Species Programme, Washington, DC

Cruscanti M, Innocenti G, Bremer JA, Galil BS (2015) First report of the brown shrimp *Penaeus aztecus* Ives, 1891 (Crustacea, Decapoda, Penaeidae) in the Tyrrhenian Sea. Marine Biodiversity Records 8, e81. https://doi.org/10.1017/S1755267215000664

Dall W, Hill BJ, Rothlisberg NW, Staples DJ (eds) (1992) The Biology of Penaeidae. Advances in Marine Biology 27. Elsevier. 504 pp

Dick JT, Platvoet D (2000) Invading predatory crustacean *Dikerogammarus villosus* eliminates both native and exotic species. Proceedings. Biological sciences/The Royal Society 267: 977-83

Duggan IC, Robinson K V, Burns CW, Banks JC, Hogg ID (2012) Identifying invertebrate invasions using morphological and molecular analyses: North American *Daphnia " pulex "* in New Zealand fresh waters. Aquatic invasions 7 (4): 585-590

Firmart C, Alibert P, Losseau M, Baroiller JF, Schliewen UK (2013) Successive invasion mediated interspecific hybridizations and population structure in the endangered *Oreochromis mossambicus*. PLos ONE 8 (10), e63880. doi:10.1371/journal.pone0063880

França RS, Suriani AL, Rocha O (2007) Composição das espécies de moluscos bentônicos nos reservatórios do baixo rio Tietê (São Paulo , Brasil) com uma avaliação do impacto causado pelas espécies exóticas invasoras. Revista Brasileira de Zoologia [online] 24 (1): 41-51

Hebert PDN, Cywinska A, Ball SL, Waard JR (2003) Biological identifications through DNA barcodes. Proceedings. Biological sciences/The Royal Society 270: 313-21

Hill AM, Lodge DM (1999) Replacement of resident crayfishes by an exotic crayfish: the roles of competition and predation. Ecological application 9: 678-690

Hoa TTT, Zwart MP, Phuong NT, Vlak JM, Jong MCM (2011) Transmission of white spot syndrome virus in improved-extensive and semi-intensive shrimp production systems: A molecular epidemiology study. Aquaculture 313: 7-14

Kapiris K, Katağan T, Ateş SA, Conides A (2012) Review of alien decapods (Crustacea) in the Aegean Sea. Journal of the Black Sea/Mediterranean Environment 18 (2): 177-187

Kearse M, Moir R, Wilson A, Stones-Havas S, Cheung M, Sturrock S, Buxton S, Cooper A, Markowitz S, Duran C, Thierer T, Ashton B, Mentjies P, Drummond A (2012) Genius Basic: an integrated and extendable desktop software platform for the organization and analysis of sequence data. Bioinformatics 28(12): 1647-1649

Leão TCC, Almeida WR, Dechoum MS, Ziller SR (2011) Espécies exóticas invasoras no nordeste do Brasil: Contextualização, manejo e políticas públicas. Recife, Cepan. 99 pp

Lis JT (1980) Fraccionation of DNA fragments by polyethylene glycol induced precipitation. In: Grossman L, Moldave K (eds) Nucleic acids Part I. Methods in enzymology 65. Elsevier. Pp 347-353

MICOA (2007) Relatório nacional sobre ambiente marinho e costeiro, Maputo

Oosterhout C Van, Mohammed RS, Xavier R, Stephenson JF, Archard GA, Hockley FA, Perkins SE, Cable J (2013) Invasive freshwater snails provide resource for native marine hermit crabs. Aquatic invasions 8 (2): 185-191

Özcan T, Ate AS, Katagan T (2008) Expanding distribution and occurence of the Indo-Pacific Stomatopod, *Erugosquilla massavensis* (Kossmann, 1880) on the Aegean coast of Turkey. Mediterranean marine science 9 (2): 115-118

Rao, GS, Radhakrishnan E, Jose J (2013) Hand book of marine prawns of India. Central Marine Fisheries Research Institute, Cochin, Kerala, India, 415 pp

Rodríguez, G, Suárez, H. (2001) Anthropogenic Dispersal of Decapod Crustaceans in Aquatic Environments. Interciencia 26 (7): 282-288

Sabour B, Reani A, EL Magouri H, Haroun R (2013) *Sargassum muticum* (Yendo) Fensholt (Fucales, Phaeophyta) in Morocco, an invasive marine species new to the Atlantic coast of Africa. Aquatic Invasions 8 (1): 97-102

Sambrook J, Fritsch EF, Maniatis T. (1989) Molecular cloning: a laboratory manual. New York, Cold Spring Harbor Laboratory Press

Scannella D, Falsone F, Geraci ML, Froglia C, Fiorentino F, Giusto GB, Zava B, Insacco G, Colloca F (2017) First report of northern brown shrimp *Penaeus aztecus* Ives, 1891 in Strait of Sicily. BioInvasions Records 6 (1): 67-72. https://doi.org/10.3391/bir. 2017.6.1.11

Shine C, Williams N, Gundling L (2000) A Guide to designing legal and institutional frameworks on alien invasive species. Environmental Policy and Law 40. IUCN, Gland, Switzerland, Cambridge and Bonn, XVI+138 pp.

Simbine L (2016) Análise da diversidade e estrutura genética *Fenneropenaeus indicus* e *Metapenaeus monoceros* com base mtDNA e uso do DNA barcoding na identificação das espécies de Peneideos (Crustacea, Decapoda, Penaeideae) da Costa de Moçambique. São Carlos. Thesis, 87 pp

Tamura K, Nei M, Kumar S (2004) Prospects for inferring very large phylogenies by using the neighbor-joining method. Proceedings of the National Academy of Sciences of the United States of America 101, 11030-5

Thompson J, Higgins D, Gibson T (1994) CLUSTAL W: improving the sensitivity of progressive multiple; sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. Nucleic Acids Research 22: 4673-4680

Torchin ME, Mitchell CE (2004) Parasites, pathogens, and invasions by plants and animals. Frontiers in Ecology and the Environment 2 (4): 183-190

Ward RD (2000) Genetics in fisheries management. Hydrobiologia 420 (1): 191-201

Wu L, Liu C, Lin S (2011) Identification of exotic Sailfin catfish species (*Pterygoplichthys*, Loricariidae) in Taiwan based on morphology and mtDNA Sequences. Zoological Studies 50 (2): 235-246

Keys and bibliography for the identification of zoeal stages of brachyuran crabs from the Western Indian Ocean

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Abstract

Approximately 430 brachyuran species have been identified as inhabiting the Western Indian Ocean (WIO), of which only 125 species have full or partial larval descriptions available. These descriptions were analysed and zoeal characters compared, in order to assess diagnostic characters for their identification. An identification key is provided for family level and identification keys to species level are provided for most families. These keys were constructed using external morphological characters whenever possible, to decrease the need for dissection and make identification as easy as possible. Only the first zoeal stage was considered, as many descriptions only consider this stage.

Keywords: Crustacea; Brachyura; larvae; morphology; key; first stage zoeas

Introduction

Brachyuran crabs are one of the major and most successful animal groups in coastal ecosystems, with 6793 species (Ng *et al*., 2008), and are one of the most abundant macroinvertebrate groups in tropical regions, in habitats such as mangroves and tidal flats (Clark and Paula, 2003). Four hundred and thirty species of brachyuran crabs have been identified as inhabiting the Western Indian Ocean (Barnard, 1950; Kensley, 1981; Emmerson, 2016).

The geographical area of this study is the Western Indian Ocean (WIO), covering the eastern coast of Africa from Somalia to Port Elizabeth in South Africa (including Kenya, Tanzania and Mozambique), and the WIO island states of Madagascar, Seychelles, Comoros, Reunion (France) and Mauritius. There is a lack of identification tools for the identification of larval crustaceans in the plankton of the WIO region, including the brachyuran crabs.

The aims of this study are to compile the available larval descriptions and produce identification keys for the families, and whenever possible for species within each family. The basic structure of the identification keys is based on the works of Rice (1980) and Clark and Cuesta (2015). The keys include the available published descriptions and unpublished descriptions from laboratory rearing of a number of species, which include *Dotilla fenestrata*, *Chaenostoma boscii*, *Macrophthalmus depressus*, *M. grandidieri*, *Astruca annulipes*, *Gelasimus vocans, Paraleptuca chlorophthalmus* and *Tubuca urvillei* (Paula *et al.*, in prep.).

Materials and methods

The list of species in the WIO (see Table 1) area was constructed mainly using the works of Barnard (1950), Kensley (1981) and Emmerson (2016) and using information from the online database GBIF (http://www.gbif.org). The structure of the identification key at family level was primarily based on the works of Rice (1980) and Clark and Cuesta (2015). The keys for individual families were based on published descriptions and own unpublished work (Paula *et al.*, in prep.). Taxonomic information from Ng *et al.* (2008) and the online database WoRMS (http://www.marinespecies.org) was revised. The identification key of families does not reflect taxonomic groupings; however, the individual family keys are organized taxonomically according to Ng *et al.* (2008).

Whenever possible external morphological characters of brachyuran zoeal stage I (see Fig. 1) were used to build the keys, however due to the restricted number of morphological features used for brachyuran larval identification some characters require dissection to be observed, such as appendage setation (see Fig. 2). This requires dissection and observation under a compound microscope.

The freshwater family Potomonautidae has been excluded from this study as only salt and brackish water species have been considered, and due to the fact that species of this family have direct development.

Identification keys

Identification Key for brachyuran families

1. Antennal exopod flat and scale-like 2
   Antennal exopod rod-like, reduced or absent, but never a flat scale 8

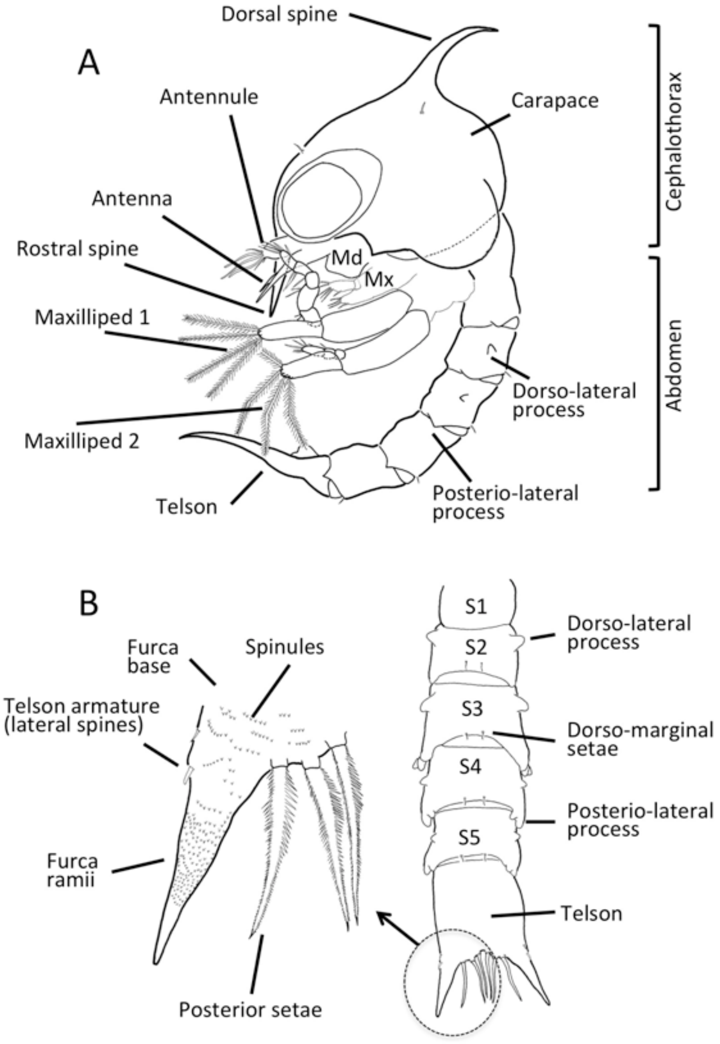

Figure 1. Main characters used in the identification keys for the first zoeal stage – external. (A) lateral view; (B) dorsal view of abdomen and detail of telson (Sesarma leptosoma, adapted from Flores et al., 2003).

2. Carapace without spines 3
Carapace with spines 4

3. Telson not furcated, triangular shaped, with long marginal plumose setae and spines on posterolateral margins DYNOMENIDAE
Telson furcated with long terminal, serrulate setae along the inner and apical part of the furcal rami HOMOLODROMIIDAE

4. Rostral spines anteriorly directed 5
Rostral spines ventrally directed 7

5. Telson furcated with long terminal, serrulate setae along the inner and apical part of the furcal rami DROMIIDAE
Telson not furcated, triangular shaped, with long marginal plumose setae and spines on posterolateral margins 6

6. Carapace lateral spines present; pleonites with dorsolateral and posterolateral processes HOMOLIDAE
Carapace lateral spines absent; pleonites without dorsolateral and posterolateral processes LATREILLIIDAE

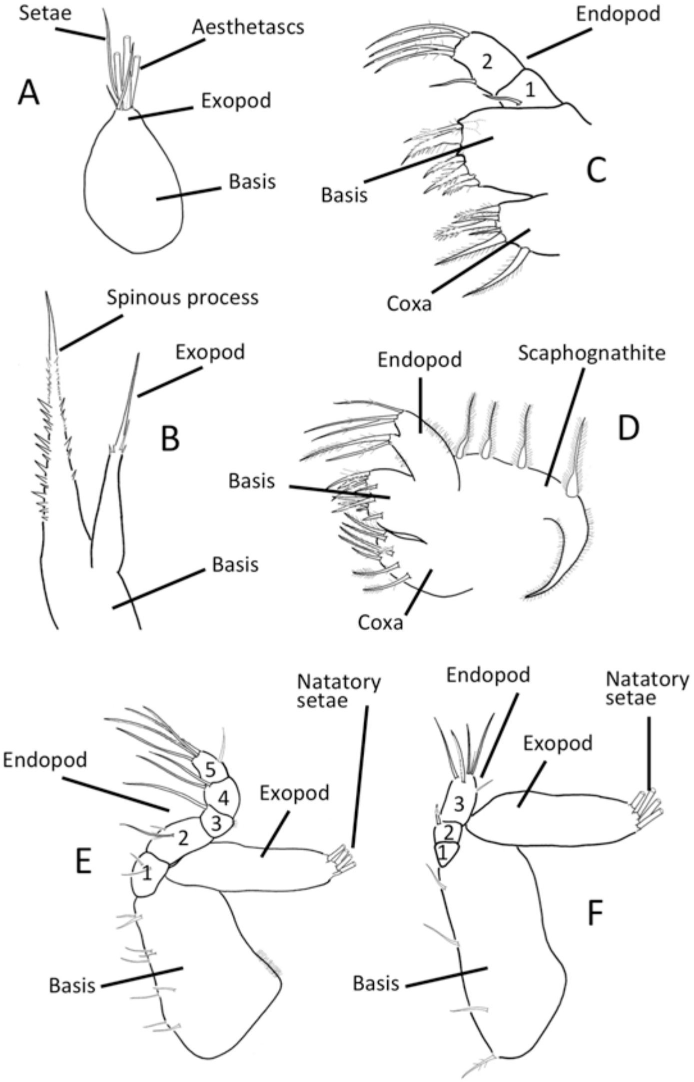

Figure 2. Main characters used in the identification keys for the first zoeal stage – appendage setation. (A) antennule; (B) antenna; (C) maxillule; (D) maxilla; (E) first maxilliped; (F) second maxilliped (Sesarma leptosoma, adapted from Flores et al., 2003).

7. Telson furcated with long terminal, serrulate setae along the inner and apical part of the furcal rami; maxillule endopod bilobed with 1+3 setae CYMONOMIDAE
Telson not furcated, triangular shaped, with long marginal plumose setae and spines on postero-lateral margins; maxillule endopod bilobed with 0+(4/5) setae RANINIDAE

8. Two zoeal stages, that is never with more than 6 natatory setae on the exopods of the maxillipeds. In stage I (with 4 natatory setae) the scaphognathite has at least 9 marginal setae. In stage II (with 6 natatory setae) there are well-developed pleopods on pleonites 2 – 5, at least as long as their respective somites. Basal segment (ischium) of endopod of first maxilliped always with 2 medial setae 9 (MAJOIDEA)
Almost always with more than two zoeal stages, so that there may be 8 or more natatory setae. In stage I the scaphognathite almost always has less than 9 marginal setae (usually 3 or 4); if there are more than 9 marginal setae in stage I, the basal segment of the first maxilliped carries 3 medial setae. Pleopods never well-developed in zoeae with 6 natatory setae on the exopods of the maxillipeds 13

9. Antennal exopod equal or longer than protopod 10
Antennal exopod shorter than protopod 12

10. Maxilla endopod with 2+2 or 3+(2/3) setae MAJIDAE (Genera *Micippa* and *Schizophrys*)
Maxilla endopod with 3+6 setae 11

11. Basis of second maxilliped with 2-3 setae (0/1,1,1); endopod of second maxilliped 3-segmented with 1,1, (4/6) setae EPIALTIDAE
Basis of second maxilliped with 0-3 setae (0/1,0/1,0/1); endopod of second maxilliped 3-segmented with 0,1, 4 setae INACHIDAE

12. Maxilla endopod not bilobed with 5 setae MAJIDAE (Genera *Eurynome* and *Maja*)
Maxilla endopod bilobed OREGONIIDAE

13. Telson furcated; constriction in proximal part and strong lateral spines in some cases; conspicuously long and unarmed furcal rami 14
Telson furcated or not; telson not constricted 15

14. Maxilulle endopod with 0+4 setae; maxilla endopod with 1+3 setae DORIPPIDAE
Maxilulle endopod with 0+6 setae; maxilla endopod with 1+5 setae ETHUSIDAE

15. Antennal exopod absent or present but reduced 16
Antennal exopod present, well developed 23

16. Telson not furcated and triangular in shape with 1 to 3 small spines at each posterolateral margin LEUCOSIIDAE
Telson furcated 17

17. Maxillule endopod with 4 or less setae; basis of first maxilliped with 10 setae 18
Maxillule endopod with 5 or more setae; basis of first maxilliped with 10 setae or less 19

18. Pleonites 3-5 with posterolateral processes, maxilla endopod with 2+3 setae DOTILLIDAE (part)
Pleonites without posterolateral processes, maxilla endopod with 1+2 setae PINNOTHERIDAE

19. Antennal exopod absent 20
Antennal exopod present but reduced 22

20. Telson furcal rami armed with dorsal and lateral spines; basis of first maxilliped with 10 setae MATUTIDAE
Telson furcal rami armed with lateral spines; basis of first maxilliped with 9 setae or less 21

21. Basis of first maxilliped with 9 setae (2,2,2,3) PALICIDAE
Basis of first maxilliped with 8 setae (2,2,2,2) GRAPSIDAE (*Metopograpsus* spp.)

22. Telson rectangular; maxilla endopod with 2+2 setae GRAPSIDAE (excluding *Metopograpsus* spp.)
Telson elongate trapezoidal, wider anteriorly; maxilla endopod with 2+3 setae HYMENOSOMATIDAE

23. Antennal exopod well developed, similar in size or longer than protopod and with medial setae 24
Antennal exopod shorter than protopod, with terminal setae and spines 33

24. Telson furca unarmed 25
Telson furca armed 26

25. Pleonal lateral expansions on pleonite 5 MACROPHTHALMIDAE

Pleonal lateral expansions on pleonites absent VARUNIDAE

26. Telson furca armed with dorsal and lateral spines 27
Telson furca armed with either dorsal or lateral spines 29

27. Posterolateral processes present on pleonites 2-5 GONEPLACIDAE
Posterolateral processes present on pleonites 3-5 28

28. Dorsolateral processes present on pleonites 2-3 PILUMNIDAE
Dorsolateral processes present on pleonites 2-4 GERYONIDAE

29. Pleonal lateral expansions present on pleonite 4 CRYPTOCHIRIDAE
Pleonal lateral expansions present on pleonites absent 30

30. Dorsolateral processes present only on pleonite 2 HEXAPODIDAE
Dorsolateral processes present on pleonites 2-3 or 2-4 31

31. Dorsolateral processes on pleonites 2-4 CAMPTANDRIIDAE
Dorsolateral processes on pleonites 2-3 32

32. Basis of second maxilliped with 4 setae; telson furca with lateral spines; maxilla endopod bilobed with 3+5 setae EURYPLACIDAE
Basis of second maxilliped with 3 setae; telson furca with lateral or dorsal spines; maxilla endopod bi-lobed with 2+3 setae DOTILLIDAE (part)

33. Dorsolateral processes only on pleonite 2 34
Dorsolateral processes on pleonites 2-3 or 2-5 38

34. Telson furcal rami armed with either dorsal spines or lateral spines 35
Telson furcal rami armed with dorsal and lateral spines 36

35. Telson furcal rami armed with dorsal spines CORYSTIDAE
Telson furcal rami armed with lateral spines MENIPPIDAE

36. Carapace lateral spines absent CARCINIDAE
Carapace lateral spines present 37

37. Posterolateral processes on pleonites 2-4 ATELECYCLIDAE
Posterolateral processes on pleonites 3-5 CANCRIDAE

38. Pleonite 1 with middorsal process 39
Pleonite 1 without any processes 40

39. Two pairs of carapace lateral spines; maxilla endopod with 3+5 setae TRAPEZIIDAE
One pair of carapace lateral spines; maxilla endopod with 1+2 setae OCYPODIDAE (*Ocypode ceratophthalmus*)

40. Dorsolateral processes on pleonites 2-5 41
Dorsolateral processes on pleonites 2-3 44

41. Telson furcal rami armed with only lateral spines 42
Telson furcal rami armed with lateral and dorsal spines 43

42. Basis of first maxilliped with 8 setae arranged 2,2,2,2 PLAGUSIIDAE
Basis of first maxilliped with 9 setae arranged 2,2,3,2 PERCNIDAE

43. Carapace lateral spines present ERIPHIIDAE
Carapace lateral spines absent CARPILIIDAE

44. Posterolateral processes on somites 2-5 or absent 45
Posterolateral processes on somites 3-5 48

45. Telson furcal rami either unarmed or armed with dorsal spines OCYPODIDAE (except *Ocypode ceratophthalmus*)

Telson furcal rami armed with dorsal and lateral spines 46

46. Ventral spines on telson furcal rami present PANOPEIDAE
Ventral spines on telson furcal rami absent 47

47. Maxilla endopod with 2+5 setae; basis of first maxilliped with 8 setae (2,2,2,2); maxillule endopod with 0+6 setae CALAPPIDAE
Maxilla endopod with 3+5 setae; basis of first maxilliped with 10 setae (2,2,3,3); maxillule endopod with 1+6 setae OZIIDAE

48. Telson furcal rami unarmed or armed with either dorsal or lateral spines 49
Telson furcal rami armed with dorsal and lateral spines 51

49. Carapace lateral spines absent SESARMIDAE
Carapace lateral spines present 50

50. Maxillule endopod with 0+4 setae; basis of second maxilliped with 3 setae (1,1,1); endopod of second maxilliped with 0,1,6 setae DOTILLIDAE (part)
Maxillule endopod with 1+5 setae; basis of second maxilliped with 4 setae (1,1,1,1); endopod of second maxilliped with 1,1,6 setae GECARCINIDAE

51. Proximal segment of maxilla endopod with 2 setae 52
Proximal segment of maxilla endopod with 3 setae 54

52. Maxillule endopod bilobed with 1+5 setae; distal segment of maxilla endopod with 3 setae TETRALIIDAE
Maxillule endopod bilobed with 1+6 setae; distal segment of maxilla endopod with 4 or more setae 53

53. Basis of first maxilliped with 10 setae; distal segment of maxilla endopod with 4 setae PORTUNIDAE
Basis of first maxilliped with 8 setae; distal segment of maxilla endopod with 5 setae PARTHENOPIDAE

54. Basis of first maxilliped with 9 setae or less 55
Basis of first maxilliped with 10 setae 56

55. Basis of first maxilliped with 8 setae (2,2,2,2); endopod of first maxilliped 5-segmented with 2,2,1,2,5 setae POLYBIIDAE
Basis of first maxilliped with 9 setae (2,2,3,2); endopod of first maxilliped 5-segmented with 3,2,1,2,5 setae AETHRIDAE

56. Endopod of first maxilliped 5-segmented with 2,2,1,2,5 setae OVALIPIDAE
Endopod of first maxilliped 5-segmented with 3,2,1,2,5 setae 57

57. Maxilla endopod bilobed with 3+5 setae XANTHIDAE
Maxilla endopod bilobed with 3+3 setae DAIRIDAE

Identification Key for:

Dromiidae

The family Dromiidae has 28 species in the WIO region, distributed in 16 genera all belonging to the subfamily Dromiinae: *Ascidiophilus caphyraeformis*, *Barnardromia bituberculata*, *B. hirsutimana*, *Conchoecetes artificiosus*, *Cryptodromia bullifera*, *C. fallax*, *Dromia dormia*, *Dromidia aegibotus*, *D. cornuta*, *D. dissothrix*, *D. hirsutissima*, *D. lepidota*, *Eudromidia frontalis*, *E. hendersoni*, *Exodromidia spinosa*, *E. spinosissima*, *Hemisphaerodromia monodous*, *Lauridromia dehaani*, *L. intermedia*, *Lewimdromia unidentata*, *Metadromia wilsoni*, *Platydromia spongiosa*, *Pseudodromia cacuminis*, *P. latens*, *P. rotunda*, *P. trepida*, *Speodromia platyarthrodes* and *Tumidodromia dormia*. This family occupies a diverse range of habitats, from the intertidal to depths of 600 meters. The zoeae of this family present a furcated telson with long terminal, serrulate setae along the inner and apical part of the furcal rami, and the rostral spine is anteriorly directed. Of the 28 species identified only two have larval descriptions: *Conchoecetes artificiosus* and *Lauridromia dehaani* by McLay *et al.* (2001).

Antennule exopod with 1 plumose seta and 6 aesthetascs; basis of first maxilliped with 12 plumose setae (arranged 3,3,3,3); coxa of first maxilliped with 2 plumose setae *Conchoecetes artificiosus*

Antennule exopod with 1 plumose seta and 5 aesthetascs; basis of first maxilliped with 11 plumose setae (arranged 2,3,3,3); coxa of first maxilliped with 1 plumose seta *Lauridromia dehaani*

Homolidae

The family Homolidae has 10 species in the WIO region distributed in seven genera, *Homola barbata, H. orientalis, Homolochunia valdividae, Ihlopsis multispinosa, Lamoha murotoensis, Latreillopsis bispinosa, L. tetraspinosa, Mohola alcocki, M. alisae* and *Paromola cuvieri*. This family is often reef-associated and it also occupies benthic habitats within the depth range 38 meters to 700 meters, although some *Paramola cuvieri* have been captured at 1212 meters (Fischer *et al.*, 1981). Of the 10 species identified only 2 have larval descripitons: *Homola barbata* by Rice and Provenzano Jr. (1970) and Clark and Cuesta (2015), and *Paromola cuvieri* by Samuelsen (1976). The zoeae of this family present an anteriorly directed rostral spine and lateral spines in the carapace, and dorsolateral and posterolateral processes in the pleonites.

Antennal exopod with 9 long plumose setae; endopod of first maxilliped 5-segmented with 1,1,1,2,5 setae; exopod of first maxilliped with 4 natatory setae *Homola barbata*

Antennal exopod with 5 or 6 long setae; endopod of first maxilliped 5-segmented with 1,1,1,2,4 setae; exopod of first maxilliped with 3 natatory setae *Paromola cuvieri*

Raninidae

The family Raninidae has five species in the WIO region distributed in four subfamilies, Lyreidinae, Notopodinae, Ranininae and Raninoidinae. The Lyreidinae subfamily is represented by one species, *Lyreidus brevifrons*; the Notopodinae subfamily is represented by two species, *Cosmonotus grayii* and *Notopus dorsipes*; the Ranininae subfamily is represented by one species, *Ranina ranina*; the Ranioidinae subfamily is represented by one species, *Raninoides barnardi*. This family, commonly known as frog crabs due to their elongated cephalothorax, consists of reef-associated and borrowing species, preferring sandy substrates. The zoeae of this family present a ventrally directed rostral spine and a non furcated telson, triangular, with long marginal plumose setae and spines on posterolateral margins. Of the five species identified, only one has a larval description: *Ranina ranina* by Sakai (1971).

Aethridae

The family Aethridae has three species in the WIO region, *Actaeomorpha erosa*, *Aethra scruposa* and *A. seychellensis*. This family is reef-associated and can be found in a depth range of 0 meters to 40 meters. The zoeae of this family have long lateral carapacae spines, one-half the length of the width of the carapace, and telson usually with 2 or 3 spines on each furca. Of the three species identified, only one has a larval description: *Aethra scruposa* by Clark (in press).

Calappidae

The family Calappidae has 12 species in the WIO region distributed in two genera, *Calappa africana, C. gallus¸C. guerini, C. hepatica, C. japonica, C. lophos, C. pustulosa, C. woodmasoni, Mursia africana, M. armata, M. cristiata* and *M. flamma*. The genus *Calappa* inhabits sandy and muddy substrates at depths of 30 meters to 380 meters, with most species inhabiting the 40-72 meters range, except for *C. hepatica* which is present in inter-infratidal habitats; while the genus *Mursia* inhabit sandy and muddy substrates at depths of 10 meters to 510 meters, mostly below the 200 meters range. The zoeae of this family present a ventrally curved rostral spine with pointed spinules along anterior half, furcated telson with 2 lateral spines on furcal rami and maxilla endopod with 2+5 setae. Of the 12 species identified only three have larval descriptions: *Calappa gallus, C. japonica* by Taishaku and Konishi (1995), and *C. lophos* by Seridji (1993) and Taishaku and Konishi (1995).

1. Rostral carapace spine with 6-10 pointed spinules along its anterior half *Calappa gallus*
Rostral carapace spine with 4-5 pointed spinules along its anterior half 2

2. Endopod of second maxilliped 3-segmented with 1,1,3 setae *Calappa japonica*
Endopod of second maxilliped 3-segmented with 1,1,4 setae *Calappa lophos*

Matutidae

The family Matutidae has one species in the WIO region, *Ashtoret lunaris*. This family, commonly known as the moon crabs, is found in sandy or muddy shores, with a preference for seagrass beds, reaching depths of up to 50 meters. The zoeae of this family do not have an antennal exopod and have a furcated telson armed with dorsal and lateral spines. The larvae of this species has been described by Seridji (1993) and Taishaku and Konishi (1995).

Atelecyclidae

The family Atelecyclidae has one species in the WIO region, *Atelecyclus rotundatus*. This family has benthic and demersal species, with depth ranges from 0 to 1200 meters. The zoeae of this family present an antennal exopod shorter than the protopod, with terminal seate and spines, the carapace presents lateral spines and the furcated telson is armed with dorsal and lateral spines, and the pleonites 2 to 4 present posterolateral processes. The larvae of this species has been described by Hong and Ingle (1987).

Carpiliidae

The family Carpillidae has two species in the WIO region, both belonging to the genus *Carpilius*; *C. convexus* and *C. maculatus*. These species inhabit rocky or coraline substrates in the littoral to sublittoral zones (depths of 0-35 meters). The zoeae of this family present short dorsal and rostral carapace spines and the first pleonite with 4 setae. Both species have larval descritions: *Carpilius convexus* and *C. maculatus* by Clark *et al.* (2005).

Carapace with 9 pairs of anterodorsal setae and lateral spines absent; endopod of maxillule 2-segmented with 1+4 setae; scaphognathite (maxilla exopod) with 15 marginal setae; coxa of maxilla bilobed with 6+4 setae *Carpilius convexus*

Carapace with 4 pairs of anterodorsal setae and lateral spines absent; endopod of maxillule 2-segmented with 1+5 setae; scaphognathite (maxilla exopod) with 17 marginal setae; coxa of maxilla bilobed with 7+4 setae *Carpilius maculatus*

Dairidae

The family Dairidae has one species in the WIO region, *Daira perlata*. This family occupies benthic habitats reaching maximum depths of 6 meters. The genus *Daira* is the only one in this family and is considered a living fossil (Busulini *et al.*, 2006). The zoeae of this family present a furcated telson with dorsal and lateral spines on furcal rami, the basis of first maxilliped with 10 setae and maxilla endopod bilobed with 3+3 setae. The larvae of *D. perlata* has been described by Clark (in press).

Dorippidae

The family Dorippidae has four species in the WIO region distributed by three genera, *Dorippe frascone*, *D. quadridens*, *Dorippoides midipes* and *Medorippe lanata*. The genus *Dorippe* inhabits bethic areas between 0-73 meters (with *D. quadridens* sometimes reaching depths of 415 meters); *Dorippoides nudipes* between depths of 2-77 meters; and *Medorippe lanata* inhabits muddy detritic areas between 10-250 meters. The zoeae of this family present long dorsal and rostral carapace spines, telson bifurcated with conspicuously long and unarmed furcal rami, with a constriction in proximal part and strong lateral spines in some cases, and maxilla endopod with 1+3 setae. Of the four species identified only two have larval descriptions: *Dorippe frascone* by Quintana (1987) and *Medorippe lanata* by Paula (1991).

Coxal endite of maxillule with 6 setae; coxal endite of maxilla with 3 setae; basial endite of maxilla bilobed with 5+5 setae *Dorippe frascone*

Coxal endite of maxillule with 5 setae; coxal endite of maxilla with 2 setae; basial endite of maxilla bilobed with 4+4 setae *Medorippe lanata*

Eriphiidae

The family Eriphiidae has three species in the WIO region, all belonging to *Eriphia* genus, *E. scabricula*, *E. sebana* and *E. smithii*. These species are intertidal and associated with reefs or rocky substrates. The zoeae of this family present dorsal and rostral carapace spines of approximately the same length, lateral carapace spine present and furcated telson with lateral and dorsal spines on each rami. All three species have larval descriptions: *Eriphia scabricula* by Clark and Paula (2003), *E. sebana* and *E. smithii* by Ko (2005).

1.Ventral margin of carapace without tubercles and setae *Eriphia scabricula*
Ventral margin of carapace with 2 small tubercles posteriorly and without setae 2

2. Antennal exopod with 3 terminal simple setae *Eriphia sebana*
Antennal exopod with 4 terminal simple setae *Eriphia smithii*

Menippidae

The family Menippidae has three species in the WIO region, *Menippe rumphii*, *Myomenippe fornasinii* and *Sphaerozius nitidus*. This family occupies several habitats: benthic, demersal, some species are reef-associated, others prefer muddy or rocky substrates and has a depth range from 0 to 800 meters. The zoeae of this family present an antennal exopod shorter than the protopod, with terminal setae and spines, the furcated telson presents lateral spines and only the second pleonite has dorsolateral processes. Of the three species identified, two have larval descriptions: *Sphaerozius nitidus* by Ko (2005) and *Menippe rumphii* by Clark (in press).

Ventral margin of carapace without setae; antennal exopod with one long terminal seta *Menippe rumphii*
Ventral margin of carapace with 2 small tubercules posteriorly; antennal exopod with two terminal simple setae *Sphaerozius nitidus*

Oziidae

The family Oziidae has four species in the WIO region, distributed by 3 genera, *Epixanthus dentatus*, *E, frontalis*, *Lydia annulipes* and *Ozius rugulosus.* This family has a varied habitat range, from demersal species to brackish and reef-associated species, within a depth range of 0 to 6 meters. The zoeae of this family present a ventrally curved rostral spine with pointed spinules along anterior half, furcated telson with 2 outer spines and ventral spines absent on furcal rami and maxilla endopod with 3+5 setae. Of the four species identified, all have larval descriptions: *Lydia annulipes*, *Epixanthus dentatus* by Clark and Paula (2003), *E. frontalis* by Clark and Paula (2003) and by Al-Aidaroos *et al*. (2014), and *Ozius rugulosus* by Kakati and Nayak (1977).

1. Basial endite of maxillule with 7 setal processes *Epixanthus dentatus*
   Basial endite of maxillule with 5 setal processes 2

2. Coxal endite of maxilla bilobed with 7+4 setae *Lydia annulipes*
   Coxal endite of maxilla bilobed with 5+4 setae 3

3. Exopod of antennule with 2 aesthetascs and 1 seta *Ozius rugulosous*
   Exopod of antennule with 5 aesthetascs and 1 seta *Epixanthus frontalis*

Goneplacidae

The family Goneplacidae has nine species in the WIO region distributed in six genera, *Carcinoplax ischurodous*, *C. longimanus*, *Entricoplax vestita*, *Goneplax clevai*, *G. rhomboides*, *Ommatocarcinus pulcher*, *Psopheticus crosnieri*, *P. stirdulans* and *Pycnoplax coryphaea*. This family is mostly benthic and demersal in depths ranging from 3 to 800 meters. The zoeae of this family present a well developed antennal exopod, similar in size or longer than protopod, telson furca armed with dorsal and lateral spines, and posterolateral processes on pleonites 2 to 5. Of the nine species identified only two have larval descriptions: *Carcinoplax longimanus* by Terada (1984) and *Goneplax rhomboides* by Ingle and Clark (1983).

Coxal endite of maxillule with 7 setae; coxal endite of maxilla bilobed with 1+3 setae *Carcinoplax longimanus*

Coxal endite of maxillule with 6 setae; coxal endite of maxilla bilobed with 4+4 setae *Goneplax rhomboides*

Hexapodidae

The family Hexapodidae has two species in the WIO region, *Hexapus stebbing* and *Spirolax spiralis*. This family is benthic with a depth range from 0 meters to 50 meters. The zoeae of this family present a well developed antennal exopod, similar in size or longer than protopod, and dorsolateral processes only on the second pleonite. Of the 2 species identified, only 1 has larval descriptions: *Spirolax spiralis* by Pereyra Lago (1988).

Leucosiidae

The family Leucosiidae has 28 species in the WIO region belonging to three subfamilies, Cryptocneminae, Ebaliinae and Leucosiinae. The Cryptocneminae subfamily is represented by two species, *Cryptocnemus holdsworthi* and *Leucisca squalina*; the Ebaliinae subfamily is represented by 24 species distributed in 13 genera, *Afrophila punctata*, *Arcania cornuta*, *A. septemspinosa*, *A. undecimspinosa*, *Ebalia agglomus*, *E. barnardi*, *E. glomus*, *E. pondoensis*, *E. tuberculata*, *E. tuberculosa*, *Heternonucia angulata*, *Hiplyra michellinae*, *H. platycheir*, *Lithadia barnardi*, *Lyphira matalensis*, *Myra fugax*, *M. subgranula*, *Nucia speciosa*, *Nursilia dentata*, *Philyra globus*, *P. samia*, *P. scabriuscula*, *Ryphila cancellus* and *Tanaoa pustulosus*; the Leucosiinae subfamily is represented by two species, *Soceulia marmorea* and *Urnalana whitei*. This family occupies a varied range of habitats, from reef-associated species to demersal and benthic species, with a depth range of 1 to 420 meters. The zoeae of this family present a non-furcated telson and the antennal exopod is absent. Of the 28 species identified only six have larval descriptions and all belong to the Ebaliinae subfamily: *Arcania septemspinosa, A. undecimspinosa*, *Hiplyra platycheir*, *Myra fugax* by Ko (2000), *Philyra globus* by Krishnan and Kannupandi (1990b) and *P. scabriuscula* by Rajabai (1960).

1. Carapace without dorsal spine 2
   Carapace with dorsal spine 3

2. Basis of first maxilliped with 8 setae, arranged 2,2,2,2 *Hiplyra platycheir*
   Basis of first maxilliped with 10 setae, arranged 2,2,3,3 *Philyra globus*

3. Coxal endite of maxillule with 5 setae 4
   Coxal endite of maxillule with 6 setae 5

4. Endopod of maxillule 2-segmented with 2+2 setae *Arcania septemspinosa*
   Endopod of maxillule 2-segmented with 0+4 setae *Myra fugax*

5. Endopod of first maxilliped 5-segmented with 2,2,1,2,5 setae *Arcania undecimspinosa*

   Endopod of first maxilliped 5-segmented with 4,0,1,0,3 setae *Philyra scabriuscula*

Epialtidae

The family Epialtide has 22 species in the WIO region distributed in 13 genera, belonging to 3 subfamilies, Epialtinae, Pisinae and Tychinae. In the subfamily Epialtinae are 11 species distributed in 6 genera, *Acanthonyx dentatus*, *A. quadridentatus*, *A. scutellatus*, *A. undulatus*, *Antilibinia smithii*, *Huenia heraldica*, *Menaethiops delagoae*, *M. fascicularis*, *M. natalensis*, *Menaethius monoceros* and *Xenocarcinus tuberculatus*; in the subfamily Pisinae are 10 species distributed by six genera, *Cyphocarcinus capreolus*, *Doclea muricata*, *Hyastenus convexus*, *H. diacanthus*, *H. spinosus*, *H. uncifer*, *Naxioides hirtus*, *Rochinia natalensis*, *R. pulchra* and *Tiarinia cornigera*; the subfamily Tychinae in the WIO area is only represented by one species, *Stilbognathus cervicornis*. This family occupies a wide range of habitats: subfamily Epialtinae mostly intertidal reaching depths of 290 meters; subfamily Pisinae intertidal, subtidal, with a depth range of 23 meters to 636 meters; subfamily Tychinae reaching depths of 62 meters. The zoeae of this family only present two zoeal stages (as do all species belonging to the superfamily Majoidea), the antennal exopod is similar in size or longer than protopod and endopod of second maxilliped three-segmented with 1,1,4/6 setae. Of the 22 species identified only three have larval descriptions: *Huenia heraldica*, *Menaethius monoceros* by Colavite *et al*. (2014) and *Doclea muricata* by Krishnan and Kannupandi (1987).

1. Carapace with dorsal spine *Doclea muricata*
   Carapace without dorsal spine 2

2. Endopod of first maxilliped 5-segmented with 3,2,1,2,4 setae *Menaethius monoceros*
   Endopod of first maxilliped 5-segmented with 3,2,1,2,5 setae *Huenia heraldica*

Inachidae

The family Inachidae has 22 species in the WIO region, distributed in 12 genera, *Achaeopsis spinulosa*, *Achaeus barnardi*, *A. curvirostris*, *A. lacertosus*, *A. laevioculis*, *A. spinossisimus*, *Camposcia retusa*, *Chorinachus dolichorhynchus*, *Cyrtomaia murrayi*, *Dorhynchus thomsoni*, *Inachus dorsettensis*, *I.guentheri*, *Macropodia falcifera*, *M. formosa*, *M. intermedia*, *M. rostrata*, *Oncinopus neptunus*, *Paratymolus barnardi*, *P. pubescens*, *Platymaia alcocki*, *P. turbynei* and *Sunipea indicus*. It has to be taken into account that recent research suggests that the genera *Cyrtomaia* and *Platymaia* could actually belong to the Oregoniidae family (Marco-Herrero *et al*., 2013). This family is found in benthic habitats, mostly in the 0 to 200 meter range, although *Dorhynchus thomsoni* has been found at 2080 meters (Rice and Hartnoll, 1983). The zoeae of this family only present two zoeal stages (as do all species belonging to the superfamily Majoidea), the antennal exopod is similar in size or longer than protopod and endopod of second maxilliped three-segmented with 0,1,4 setae. Of the 22 species identified only three have larval descriptions: *Dorhynchus thomsoni* by Williamson (1982), *Inachus dorsettensis* by Lebour (1927) and by Ingle (1977), and *Macropodia rostrata* by Ingle (1982).

1. Endopod of first maxilliped 5-segmented with 3,2,1,2,3 setae *Dorhynchus thomsoni*
   Endopod of first maxilliped 5-segmented with 3,2,1,2,5 setae 2

2. Distal segment of endopod of maxillule with 4 setae; basis of second maxilliped without setae *Inachus dorsettensis*
   Distal segment of endopod of maxillule with 3 setae; basis of second maxilliped with 1 seta *Macropodia rostrata*

Majidae

The family Majidae has 12 species in the WIO region, distributed in nine genera, *Choniognathus elegans*, *Entomonyx soinosus*, *Eurynome aspera*, *Maja cornuta*, *M. squinado*, *Majella brevipes*, *Micippa philyra*, *M. thalia*, *Prismatopus longispinus*, *P. tosaensis*, *Sakaija africana* and *Schizophrys aspera*. This family occupies various habitats, such as benthic, demersal and reefs. The zoeae of this family only present two zoeal stages (as do all species belonging to the superfamily Majoidea), anterior seta on inner lateral margin of carapace. Of the 12 species identified five have larval descriptions: *Eurynome aspera* by Salman (1982), *Maja squinado* by Lebour (1927) and by Guerao *et al.* (2008), *Micippa philyra* by Ko (1995b), *M. thalia* by Gore *et al*. (1982), and *Schizophrys aspera* by Ghory (2012).

(Genera *Micippa* and *Schizophrys*)

1. Antennule with 6 aesthetascs and 1 seta *Schizophrys aspera*
   Antennule with 3 aesthetascs and 1 seta 2

2. Antennal spinous process slightly longer than exopod *Micippa philyra*
   Antennal spinous process slightly shorter than exopod *Micippa thalia*

(Genera *Eurynome* and *Maja*)

1. Lateral spines of carapace absent; basis of first maxilliped with 10 setae, arranged 2,2,3,3 *Eurynome aspera*
   Lateral spines of carapace present; basis of first maxilliped with 9 setae, arranged 2,2,2,3 *Maja squinado*

Pilumnidae

The family Pilumnidae has 14 species in the WIO region belonging to three subfamilies, Eumodoninae, Pilumninae and Xenophthalmodinae. The Eumodoninae subfamily is represented by two species, *Eumedonus niger* and *Gonatonotus granulosus*; the Pilumninae subfamily is represented by nine species distributed in five genera, *Actumnus setifer*, *Benthopanope indica*, *Eurycarcinus natalensis*, *Pilumnus dofleini*, *P. longicornis*, *P. minutus*, *P trichophoroides*, *P. vespertilio* and *Serenepilumnus pisifer*; the Xenophthalmodinae subfamily is represented by three species belonging to the genus *Xerophthalmodes*, *Xerophthalmodes brachyphallus*, *X. dolichophallus* and *X. moebii*. This family includes demersal, benthic and reef-associated species and occurs within a depth range of 0 meters to 33 meters. The zoeae of this family present a well developod antennal exopod, similar in size or longer than protopod, a furcated telson armed with dorsal and lateral spines and dorsolateral processes on pleonites 2 and 3. Of the 14 species identified only six have larval descriptions, all belonging to the Pilumninae subfamily: *Actumnus setifer* by Clark and Ng (2004), *Benthopanope indica* by Ko (1995a), *Eurycarcinus natalensis*, *Pilumnus longicornis* by Clark and Paula (2003), *P. minutus* by Ko (1994), and *P. vespertilio* by Lim and Tan (1979) and by Clark and Paula (2003).

1. Antennule with 3 aesthetascs 2
Antennule with 4 aesthetascs 3

2. Right molar process of mandible with 5 teeth *Benthopanope indica*
Right molar process of mandible with 4 teeth *Pilumnus minutus*

3. Dorsal carapace spine slightly longer than rostral spine *Pilumnus longicornis*
Dorsal carapace spine at least 2 times longer than rostral spine 4

4. Dorsal carapace spine 2 times longer than rostral spine *Actumnus setifer*
Dorsal carapace spine 3 times longer than rostral spine 5

5. Third maxilliped present and biramous *Pilumnus vespertilio*
Third maxilliped absent *Eurycarcinus natalensis*

Ovalipidae

The family Ovalipidae has three species in the WIO region, *Ovalipes iridescens*, *O. punctatus* and *O. trimaculata*. This family is benthic and occurs within the 0 meters to 50 meters depth range, although some species occur at 580 meters. As part of the Portunoidea superfamily these species are commonly known as swimming crabs. The zoeae of this family present a furcated telson with dorsal and lateral spines on furcal rami, the basis of first maxilliped with 10 setae and maxilla endopod bilobed with 3+4 setae. Of the three species, one has a larval description: *Ovalipes trimaculata* by Schoeman and Cockcroft (1996).

Portunidae

The family Portunidae has 38 species in the WIO region distributed in six subfamilies, Caphyrinae, Carupinae, Lupocyclinae, Podophthalminae, Portuninae and Thalamitinae. The Caphyrimae subfamily is represented by five species distributed in three genera, *Caphyra alata*, *C. unidentata*, *Coelocarcinus foliatus*, *Lissocarcinus laevis* and *L. orbicularis*; the Carupinae subfamily is represented by one species, *Carupa tenuipes*; the Lupocyclinae subfamily is represented by one species, *Lupocyclus tugelae*; the Podophthalminae subfamily is represented by one species, *Podophthalmus vigil*; the Portuninae subfamily is represented by 10 species distributed in four genera, *Carupella natalensis*, *Cycloachelous granulatus*, *C. orbicularis*, *Portunus argentatus*, *P. gladiator*, *P. hastatoides*, *P. pelagicus*, *P. sanguinolentus*, *P. segnis* and *Scylla serrata;* the Thalamitinae subfamily is represented by 20 species distributed in two genera, *Charybdis africana*, *C. annulata*, *C. feriata*, *C. hellerii*, *C. natator*, *C. orientalis*, *C. smithii*, *C. variegata*, *Thalamita admete*, *T. bevisi*, *T. bouvieri*, *T.crenata*, *T. danae*, *T. delagoae*, *T. helleri*, *T. integra integra*, *T. picta*, *T. prymna*, *T. sima* and *T. woodmasoni*. This family is benthic and is found on sandy or muddy substrates, as long as some rocks are nearby for shelter, these crabs are mostly found in the intertidal zone within the depth range of 0 - 70 m (although some species have been found at depths of 400m). As part of the Portunoidea superfamily these species are commonly known as swimming crabs. The zoeae of this family present a furcated telson with dorsal and lateral spines on furcal rami, the basis of first maxilliped with 10 setae and maxilla endopod bilobed with 2+4 setae. Of the 38 species identified, 11 have larval descriptions: *Portunus pelagicus* by Shinkarenko (1979) and by Josileen and Menon (2004), *P. sanguinolentus*, *Scylla serrata* by Naidu (1955), *Charybdis annulata*, *C. natator*, *C. orientalis*, *C. variegata* by Islam *et al.* (2000), *C. feriata* by Motoh and Villaluz (1976) and by Fielder *et al.* (1984), *C. hellerii* by Dineen *et al.* (2001), *Thalamita crenata* by Krishnan and Kannupandi (1990a), and *T. danae* by Krishnan and Kunnapandi (1988b).

1. Basial endite of maxillule with 4 setae *Thalamita crenata*
   Basial endite of maxillule with 5 or more setae 2

2. Exopod of antennule with 5 aesthetascs *Thalamita danae*
   Exopod of antennule with 2 or 3 aesthetascs 3

3. Exopod of antennule with 2 aesthetascs 4
   Exopod of antennule with 3 aesthetascs 6

4. Basis of first maxilliped with 4 setae *Scylla serrata*
   Basis of first maxilliped with 8 or 10 setae 5

5. Basis of first maxilliped with 8 setae *Portunus sanguinolentus*
   Basis of first maxilliped with 10 setae *Charybdis helleri*

6. Coxal endite of maxilla bilobed with 3+3 setae 7
   Coxal endite of maxilla bilobed with 2+3 setae 9

7. Endopod of second maxilliped 4-segmented *Portunus pelagicus*
   Endopod of second maxilliped 3-segmented 8

8. Basis of first maxilliped with 10 setae *Charybdis variegata*
   Basis of first maxilliped with 12 setae *Charybdis orientalis*

9. Endopod of second maxilliped with 1,1,5 setae *Charybdis annulata*
   Endopod of second maxilliped with 1,1,4 setae 10

10. Basial endite of maxilla bilobed with 5+4 setae *Charybdis natator*
    Basial endite of maxilla bilobed with 4+4 setae *Charybdis feriata*

Tetraliidae

The family Tetraliidae has four species in the WIO region distributed in two genera, *Tetralia cinctipes*, *T. glaberrima*, *T. rubridactyla* and *Tetraloides nigrifrons*. This family consists of reef-associated species, all members of this family are obligate associates of cnidarians (Castro, 1997), giving them the common designation of coral crabs. The zoeae of this family present a furcated telson with dorsal and lateral spines on furcal rami, the basis of first maxilliped with 10 setae and maxilla endopod bilobed with 2+3 setae. Of the four species identified two have larval descriptions: *Tetralia glaberrima* by Clark and Galil (1988) and *T. rubridactyla* by Clark and Ng (2006).

Endopod of first maxilliped 5-segmented with 2,2,1,2,5 *Tetralia glaberrima*

Endopod of first maxilliped 5-segmented with 3,2,1,2,5 *Tetralia rubridactyla*

Trapeziidae

The family Trapeziidae has 12 species in the WIO region distributed in two genera, *Quadrella boopsis*, *Q. coronata*, *Q. maculosa*, *Q. serenei*, *Trapezia bidentata*, *T. cymodoce*, *T. digitalis*, *T. guttata*, *T. lutea*, *T. richtersi*, *T. rufopunctata* and *T. speciosa*. This family consists of reef-associated species, and like the Tetraliidae all members of this family are obligate associates of cnidarians (Castro, 1997), giving them the common designation of coral crabs. The adults are more often identified by the colour patterns than by morphological characters (Castro, 1997). The zoeae of this family present an antennal exopod shorter than protopod and a middorsal process on pleonite 1. Of the 12 species identified six have larval descriptions: *Quadrella maculosa*, *Q. serenei*, *Trapezia richtersi* by Clark and Ng (2006), *T. bidentata*, *T. digitalis* by Al-Aidaroos (1992), and *T. cymodoce* by Clark and Galil (1988).

1. Ventral margin of carapace without denticles or setae 2
   Ventral margin of carapace with minute denticles and without setae 4

2. Dorsal spine of carapace spinulate *Quadrella maculosa*
   Dorsal spine of carapace not spinulate 3

3. Carapace with one pair of lateral spines; maxillule endopod 2-segmented with 1+5 setae; coxa of first maxilliped with one seta *Trapezia richtersi*
   Carapace with 2 pairs of lateral spines; maxillule endopod 2-segmented with 1+6 setae; coxa of first maxilliped without setae *Quadrella serenei*

4. Antennule with 4 aesthetascs *Trapezia cymodoce*
   Antennule with 5 aesthetascs 5

5. Prong of telson about twice of length of lateral spine; 3 pairs of inner setae, outer most about 3/4 length of prong *Trapezia bidentata*
   Prong of telson less than twice of length of

lateral spine; 3 pairs of inner setae, outer most about as long as prong *Trapezia digitalis*

Panopeidae

The family Panopeidae has one species in the WIO region, *Panopeus africanus*. This family, commonly known as mud crabs, is benthic and usually occurs in muddy substrates, reaching depths of 20 meters. The zoeae of this family present a furcated telson armed with dorsal, ventral and lateral spines and dorsolateral processes on pleonites 2 and 3. The larvae of *P. africanus* have been described by Rodríguez and Paula (1993).

Xanthidae

The family Xanthidae has 66 species in the WIO region distributed by 11 subfamilies, Actaeinae, Banareiinae, Chlorodiellinae, Cymoinae, Etisinae, Euxanthinae, Kraussiinae, Liomerinae, Polydectinae, Xanthinae and Zosiminae. The Actaeinae subfamily is represented by 13 species distributed in 8 genera, *Actaea polyacantha*, *A. savignii*, *A. spinosissima*, *Actaeodes hirsutissimus*, *A. tomentosus*, *Epiactaea nodulosa*, *Forestiana depressa*, *Gaillardiellus rueppelli*, *Paractaea rebieri*, *P. rufopunctata*, *Psaumis cavipes*, *Pseudoliomera speciosa* and *P. variolosa*; the Banareiinae subfamily is represented by one species, *Banareia parvula*; the Chlorodiellinae subfamily is represented by nine species distributed in five genera, *Chlorodiella laevissima*, *C. nigra*, *Cyclodius obscurus*, *C. ungulatus*, *Luniella pugil*, *Phymodius ungulatus*, *Pilodius areolatus*, *P. melanospinis* and *P. pilumnoides*; the Cymoinae subfamily is represented by three species, *Cymo andreossyi*, *C. melanodactylus* and *C. quadrilobatus*; the Etisinae subfamily is represented by three species, *Etisus anaglyptus*, *E. electra* and *E. laevimanus*. The Euxanthinae subfamily is represented by four species distributed in three genera, *Hypocolpus diverticulatus*, *Medaeops granulosus*, *M. neglectus* and *Monodaeus tuberculidens*; the Kraussiinae subfamily is represented by one species, *Kraussia rugulosa*; the Liomerinae subfamily is represented by eight species distributed in two genera, *Liomera bella*, *L. cinctimanus*, *L. monticulosa*, *L. rugata*, *L. stimpsonii*, *L. tristis*, *Neoliomera sabaea* and *N. themisto*; the Polydectinae subfamily is represented by three species, *Lybia leptochelis*, *L. plumosa* and *L. tessellata*; the Xanthinae subfamily is represented by nine species distributed in five genera, *Lachnopodus subacutus*, *Leptodius exaratus*, *L. sanguineus*, *Macromedaeus quinquedentatus*, *M. voeltzkowi*, *Neoxanthias impressus*, *Xanthias lamarckii*, *X. maculatus* and *X. punctatus*; the Zosiminae subfamily is represented by 12 species distributed in seven genera, *Atergatis floridus, A. granulatus*, *A. ocyroe*, *A. roseus*, *Atergatopsis obesa*, *A. signata*, *Lophozozymus dodone*, *Paratergatis longimanus*, *Platypodia granulosa*, *Zosimus aeneus*, *Zozymodes cavipes* and *Z. xanthoides*. Species belonging to this family are usually reef-associated species, reaching depths of 50 meters, although most are in the 0 meters to 10 meters range; these species are commonly referred to as mud crabs, pebble crabs or rubble crabs. The zoeae of this family present a furcated telson with dorsal and lateral spines on furcal rami, the basis of first maxilliped with 10 setae and maxilla endopod bilobed with 3+5 setae. Of the 66 species identified only 20 have larval descriptions: *Actaeodes hirsutissimus*, *A. tomentosus* by Clark and Al-Aidaroos (1996), *Epiactaea nodulosa, Psaumis cavipes* by Clark (in press), *Pseudoliomera speciosa* by Clark and Galil (1998), *Cymo andreossyi, C. quadrilobatus* by Al-Haj *et al.* (2017), *C. melanodactylus* by Al-Haj *et al.*(2017) and by Clark (in press), *Etisus anaglyptus* by Al-Haj and Al-Aidaroos (2017) and by Clark (in press), *E. electra* by Al-Haj and Al-Aidaroos (2017), *E. laevimanus* by Suzuki (1978), *Medaeops granulosus* by Clark (in press), *Liomera bella* by Yang and Ko (2005) and by Clark (in press), *L. cinctimanus* by Clark (in press), *Lybia plumosa* and *Zozymodes xanthoides* by Clark and Paula (2003), *Lachnopodus subacutus* by Clark (in press), *Leptodius exaratus* by Clark and Paula (2003) and by Al-Aidaroos *et al.* (2017), *L. sanguineus* by Clark (in press), and *Atergatis floridus* by Tanaka and Konishi (2001).

1. Rostral spine equal in length or longer than antennal protopod 2
   Rostral spine shorter than antennal protopod 9

2. Rostral spine equal in length to antennal protopod 3
   Rostral spine longer than antennal protopod 4

3. Endopod of second maxilliped 3-segmented with 1,1,5 setae *Medaeops granulosus*
   Endopod of second maxilliped 3-segmented with 1,1,6 setae *Pseudoliomera speciosa*

4. Basial endite of maxilla with 4+4 setae *Etisus laevimanus*
   Basial endite of maxilla with 5+4 setae 5

5. Coxal endite of maxillule with 8 setae *Epiactaea nodulosa*
   Coxal endite of maxillule with 7 setae 6

6. Antennule exopod with 3aesthetascs and 1 terminal seta *Atergatis floridus*

Antennule exopod with 4 aesthetascs and 1 terminal seta 7

7. Endopod of second maxilliped 3-segmented with 1,1,5 setae *Leptodius exaratus*
   Endopod of second maxilliped 3-segmented with 1,1,6 setae 8

8. Dorsal spine twice as long as rostral spine *Psaumis cavipes*
   Dorsal spine equal in length as rostral spine *Zozymodes xanthoides*

9. Antennal exopod with 1 terminal seta 10
   Antennal exopod with 3 terminal setae 13

10. Antennule exopod with 3 terminal aesthetascs and 2 terminal setae *Actaeodes hirsutissimus*
    Antennule exopod with 4 terminal aesthetascs and 1 terminal seta 11

11. Endopod of second maxilliped 3-segmented with 1,1,6 setae *Etisus anaglyptus*
    Endopod of second maxilliped 3-segmented with 1,1,5 setae 12

12. Antennule exopod with 4 broad and long aesthetascs; antennal exopod ca. 6% length of protopod *Etisus electra*
    Antennule exopod with 2 broad and 2 slender aesthetascs; antennal exopod ca. 14% length of protopod *Leptodius sanguineus*

13. Endopod of second maxilliped 3-segmented with 1,1,5 setae 14
    Endopod of second maxilliped 3-segmented with 1,1,6 setae 16

14. Maxilla endopod bilobed with 2+5 setae *Lachnopodus subacutus*
    Maxilla endopod bilobed with 3+5 setae 15

15. Basial endite of maxillule with 5 setae *Lybia plumosa*
    Basial endite of maxillule with 6 setae *Cymo andreossyi*

16. Antennule exopod with 3 terminal aesthetascs and 3 setae *Actaeodes tomentosus*
    Antunnule exopod with 4 terminal aesthetascs and 1 seta 17

17. Lateral carapace spines short and spinulated 18
    Lateral carapace spines short and not spinulated 19

18. Antennal exopod ca. 24% of protopod/somites 2-5 with short posterolateral spinous processes *Cymo quadrilobatus*
    Antennal exopod ca. 13% of protopod/somites 3-5 with short posterolateral spinous processes *Cymo melanodactylus*

19. Dorsal spine spinulate; antennal exopod ca. 13% of protopod *Liomera bella*
    Dorsal spine not spinulate; antennal exopod ca. 11.2% of protopod *Liomera cinctimanus*

Cryptochiridae

The family Cryptochiridae has two species in the WIO region, *Cryptochirus coralliodytes* and *Hapalocarcinus marsupialis*. This family is reef-associated, living in shallow waters and forms associations with stony corals, causing the formation of galls in the coral structure, earning the common name of gall crabs or coral gall crabs (Johnsson *et al.*, 2006). The zoeae of this family present pleonal lateral expansions on pleonite 4 and a furcated telson armed with lateral spines. Of the two species, one has a larval description: *Hapalocarcinus marsupialis* by Gore *et al*. (1983).

Gecarcinidae

The family Gecarcinidae has one species in the WIO region, *Cardisoma carnifex*. This family, known as land crabs, is terrestrial with spawning and larval development occuring in marine habitats. The zoeae of this family present an antennal exopod shorter than protopod, lateral carapace spines and maxillule endopod with 1+5 setae. The larvae of *C. carnifex* has been described by Flores *et al*. (2003).

Grapsidae

The family Grapsidae has 10 species in the WIO region distributed in five genera, *Geograpsus stormi*, *Grapsus fourmanoiri*, *G. tenuicrustatus*, *Metopograpsus messor*, *M. thukuhar*, *Pachygrapsus minutus*, *P. plicatus*, *Planes major*, *P. marinus* and *P. minutus*. This family is mostly reef-associated, reaching depths of 10 meters (most common range 0-6 meters). The zoeae of this family present a rectangular telson and a maxilla endopod with 2+2 setae. Of the 10 species identified seven have larval descriptions: *Grapsus fourmanoiri*, *G. tenuicrustatus*, *Metopograpsus messor*, *Pachygrapsus minutus*, *P. plicatus* by Flores *et al*. (2003), *Planes marinus* by Wear (1970), and *P. minutus* by Cuesta *et al*. (1997).

1. Antennal exopod absent *Metopograpsus* spp
   Antennal exopod present but reduced 2

2. Dorsal carapace spine long *Planes marinus*
   Dorsal carapace spine short 3

3. Lateral carapace spines minute and as small hooked projections *Planes minutus*
   Lateral carapace spines absent 4

4. Coxal endite of maxilla bilobed with 4+5 setae 5
   Coxal endite of maxilla bilobed with 5+4 setae 6

5. Telson with 2 lateral pairs of spines, the posterior one smaller *Grapsus fourmanoiri*
   Telson with 2 lateral pairs of spines, the posterior one larger *Grapsus tenuicrustatus*

6. Telson with 2 posterolateral pairs of spines of similar size *Pachygrapsus minutus*
   Telson with 2 posterolateral pairs of spines, the posterior one larger *Pachygrapsus plicatus*

Plagusiidae

The family Plagusiidae has five species in the WIO region distributed in 4 genera, *Euchirograpsus polyodous*, *Guinusia chabrus*, *Miersiograpsus kingsleyi*, *Plagusia depressa* and *P. squamosa*. This family occupies mostly intertidal and subtidal habitats. The zoeae of this family present a furcated telson armed with lateral spines and the basis of the first maxilliped with 8 setae. Of the 5 species identified 2 have larval description: *Guinusia chabrus* by Schubart and Cuesta (2010), and *Plagusia depressa* by Wilson and Gore (1980).

Basis of first maxilliped with 8 setae, arranged 2,2,2,2; antennal exopod less than 1/4 length of protopod *Plagusia depressa*

Basis of first maxilliped with 10 setae, arranged 2,2,3,3 antennal exopod less than 1/6 length of protopod *Guinusia chabrus*

Sesarmidae

The family Sesarmidae has 13 species in the WIO region distributed in seven genera, *Chiromantes eulimene*, *C. ortmanni*, *Neosarmatium africanum*, *N. meinerti*, *N. smithi*, *Parasesarma catenatum*, *P. leptosoma*, *P. plicatum*, *Perisesarma guttatum*, *P. samawati*, *Sarmatium crassum*, *Selatium elongatum* and *Sesarmoides longipes.* This family consists of semi-terrestrial and tree-climbing species (some genera like *Sesarma*, *Metopaulias* and *Geosesarma* are true terrestrial crabs and do not need to return to the sea for spawning (Schubart *et al*., 2003)) and can be found mainly in mangroves. The zoeae of this family present an antennal exopod shorter than protopod, lateral carapace spines are absent and maxillule endopod with 1+5 setae. Of the 13 species identified eight have larval descriptions: *Chiromantes eulimene* by Pereyra Lago (1993b), by Flores *et al*. (2003) and by Guerao *et al.* (2011), *C. ortmanni* by Guerao *et al.* (2012), *Neosarmatium meinerti* by Pereyra Lago (1989) and by Flores *et al*. (2003), *Parasesarma catenatum* by Pereyra Lago (1987) and by Flores *et al*. (2003), *P. plicatum* by Selvakumar (1999), *P. leptosoma*, *Sarmatium crassum* by Flores et al. (2003), and *Perisesarma guttatum* by Pereyra Lago (1993a).

1. Antennal exopod with 4 or more setae 2
   Antennal exopod with 3 or less setae 4

2. Antennal exopod with 5 setae *Parasesarma leptosoma*
   Antennal exopod with 4 setae 3

3. Antennule with 3 unequal terminal aesthetascs *Sarmatium crassum*
   Antennule with 5 terminal aesthetascs *Chiromantes ortmanni*

4. Antennule with 3 aesthetascs 5
   Antennule with 4 aesthetascs 6

5. Coxal endite of maxillule with 6 setae; basis of first maxilliped with 8 setae *Parasesarma catenatum*
   Coxal endite of maxillule with 5 setae; basis of first maxilliped with 10 setae *Parasesarma plicatum*

6. Antennal exopod with 2 setae *Perisesarma guttatum*
   Antennal exopod with 3 setae 7

7. Coxal endite of maxillule with 5 setae *Neosarmatium meinerti*
   Coxal endite of maxillule with 6 setae *Chiromantes eulimene*

Varunidae

The family Varunidae has seven species in the WIO region distributed in three subfamilies, Cyclograpsinae, Gaeticinae and Varuninae. The Cyclograpsinae is represented by three species, *Cyclograpsus* *punctatus*, *Parahelice balssi* and *Pseudohelice subquadrata*; the Gaeticinae subfamily is represented by one species, *Brankocleistostoma fossulum*; the Varuninae subfamily is represented by three species, *Pseudograpsus elongatus*, *Ptychognathus onyx* and *Varuna litterata*. This family is predominantly found in the intertidal zone, on muddy or rocky substrates. The zoeae of this family present a furcated unarmed telson and an antennal exopod well developed, similar in size or longer than protopod. Of these seven species, one has a larval description: *Cyclograpsus punctatus* by Fagetti and Campodonico (1971).

Dotillidae

The family Dotillidae has two species in the WIO region, *Dotilla fenestrata* and *Lazarocleistostoma dentatum*. This family is found in the intertidal zone on sandy beaches; the genera *Dotilla* and *Scopimera* live in burrows where at high tides they trap air, forming bubbles that allow them to breathe, thus earning them the common name sand bubbler crabs. The zoeae of this family are very diverse and as such it is very difficult to determine defining characters. Of these 2 species, one has a larval description: *Dotilla fenestrata* by Paula *et al.* (in prep.).

Macrophthalmidae

The family Macrophthalmidae has eight species in the WIO region belonging to two subfamilies, Ilyograpsinae and Macrophthalminae. The Ilyograpsinae subfamily is represented by two species *Ilyograpsus paludicola* and *I. rhizophorae*; the Macrophthalminae subfamily is represented by six species distributed in 3 genera, *Chaenostoma boscii*, *C. sinuspersici*, *Macrophthalmus convexus*, *M. depressus*, *M. grandidieri* and *Venitus latreillei*. This family is benthic, reaching depths of 0 to 5 meters and prefers brackish habitats. The zoeae of this family present a furcated unarmed telson, a well developed antennal exopod, similar in size or longer than protopod and pleonal expansions on pleonite 5. Of the eight species identified five have larval descriptions: *Ilyograpsus paludicola* by Flores *et al.* (2003), *Chaenostoma boscii*, *Macrophthalmus depressus*, *M. grandidieri* by Paula *et al.* (in prep.) and *Venitus latreillei* by Selvakumar *et al.* (1988).

1. Dorsal carapace spine absent *Ilyograpsus paludicola*
   Dorsal carapace spine present 2

2. Lateral carapace spine present *Venitus latreillei*
   Lateral carapace spine absent 3

3. Denticles present in pleonite 4 *Macrophthalmus depressus*
   Denticles present in pleonites 4 and 5 4

4. Dorsal carapace spine with half the length of carapace; posterolateral margin of carapace without teeth and slightly crenulated; antennal exopod with 1/3 length of protopod *Chaenostoma boscii*
   Dorsal carapace spine with 5/8 length of carapace; posterolateral margin of carapace with a small tooth and slightly crenulated; antennal exopod with 1/4 length of protopod *Macrophthamus grandidieri*

Ocypodidae

The family Ocypodidae has 11 species in the WIO region belonging to two subfamilies, Ocypodinae and Gelasiminae. The Ocypodinae subfamily is represented by four species belonging to the genus *Ocypode*, *Ocypode ceratophthalmus*, *O. cordimana*, *O. madagascariensis* and *O. rydery*; the Gelasiminae subfamily is represented by seven species distributed in five genera, *Astruca annulipes*, *Cranuca inversa*, *Gelasimus hesperiae, G. vocans, Paraleptuca chlorophthalmus*, *P. crassipes* and *Tubuca urvillei*. This family is semi-terrestrial and can be found in mangroves, salt marshes, sandy or muddy beaches, mostly in the intertidal zone. The zoeae of this family are very diverse and as such it is very difficult to determine defining characters. Of the 11 species identified six have larval descriptions: *Ocypode ceratophthalmus*, *O. cordimana* by Jiang *et al.* (2014), *Astruca annulipes*, *Gelasimus vocans*, *Paraleptuca chlorophthalmus* and *Tubuca urvillei* by Paula *et al.* (in prep.).

1. Lateral carapace spine present 2
   Lateral carapace spine absent 3

2. Pleonite 1 without rounded posterolateral processes *Ocypode cordimana*
   Pleonite 1 with rounded posterolateral processes *Ocypode ceratophthalmus*

3. Denticles absent on pleonites 4 and 5 4
   Denticles present on pleonites 4 and 5 5

4. Dorsal spine of carapace 1/3 length of carapace; rostral spine 1/3 bigger than antenna; telson forks with numerous small spines and denticles; basis of first maxilliped with 8 setae (1,2,3,2) *Astruca annulipes*

Dorsal spine of carapace 1/2 length of carapace; rostral spine twice the length of antenna; telson forks with numerous small spines and without denticles; basis of first maxilliped with 9 setae (2,2,3,2) *Tubuca urvillei*

5. Rostral spine with 1/4 length of antenna; dorsal spine of carapace with 1/3 length of carapace; mandible incisive process with 3 teeth projections and 1 subterminal tooth; basis of first maxilliped with 9 setae (2,2,3,2) *Gelasimus vocans*
Rostral spine with 3/4 length of antenna; dorsal spine of carapace with 1/6 length of carapace; mandible incisive process with 5 teeth projections and 2 subterminal teeth; basis of first maxilliped with 10 setae (3,2,3,2) *Paraleptuca chlorophthalmus*

Hymenosomatidae

The family Hymenosomatidae has six species in WIO region, distributed in five genera, *Elamena mathoei*, *Halicarcinus planatus*, *Hymenosoma geometricum*, *H. orbiculare*, *Neorhynchoplax bovis* and *Trigonoplax unguiformis*. This family occupies a diverse range of habitats, from estuarine to subtidal reaching depths of 270 meters. The zoeae of this family present a reduced antennal exopod and an eloganted trapezoidal telson, wider anteriorly. Of the six species identified four have larval descriptions: *Elamena mathoei* by Krishnan and Kannupandi (1988a), *Halicarcinus planatus* by Boschi *et al*. (1969), *Hymenosoma orbiculare* and *Trigonoplax unguiformis* by Dornelas *et al*. (2003).

1. Dorsal carapace spine absent 2
Dorsal carapace spine present 3

2. Basial endite of first maxilliped with 9 setae (2,2,2,3) *Halicarcinus planatus*
Basial endite of first maxilliped with 10 setae (2,2,3,3) *Elamena mathoei*

3. Coxal endite of maxilla with 1 seta *Trigonoplax unguiformis*
Coxal endite of maxilla with 2 setae *Hymenosoma orbiculare*

Discussion and conclusion

Four hundred and thirty species of Brachyuran crabs have been identified as inhabiting the WIO region, of which 125 (about 29%) have larval descriptions available. The most representative groups present in the WIO region are the families Xanthidae (66 species present), Portunidae (38 species present) and the Leucosiidae (28 species present). The species of some families present in the WIO region, such as Raninidae or Panopeidae, have larval descriptions available for only one of the species. For these families it was not possible to provide specific keys. The families Cyclodorippidae, Dairoididae, Acidopsidae, Chasmocarcinidae, Mathildellidae, Pseudoziidae, Retroplumidae and Trichopeltariidae are not included in the identification key of families because no larval description was found for these families, not allowing determining the diagnostic familial characteristics to be identified. In the case of the families Cymonomidae, Dynomenidae, Homolodromiidae, Latreillidae, Cancridae, Corystidae, Ethusidae, Palicidae, Oregoniidae, Parthenopidae, Carcinidae, Geryonidae, Polybiidae, Percnidae, Camptandriidae and Pinnotheridae there are larval descriptions available but not for species present in the WIO region.

Many challenges arose when developing the identification key for families. For example, separating the families Portunidae, Parthenopidae, Polybiidae, Aethridae, Ovalipidae, Xanthidae and Dairidae was particularly difficult and was only possible using the setation of segments of the first maxilliped and of the maxilla (Clark and Cuesta, 2015). Within the families there is also a high level of intraspecific similarity requiring the use of characters exposed through dissection to differentiate between species. This is a concern in families that have a high percentage of non-described species, as it increases the probability of mistaking a described species for a non-described one.

These keys should be used with caution as only 29% of the species that are present in the WIO region have larval descriptions and because only the first zoeal stage was considered, although most morphological characters used are, in general, conservative throughout the larval series. There is still much descriptive work required for these keys to become more complete as far as the diversity of the brachyuran fauna that inhabits the WIO area is concerned. Most of the species in this geographic area are either non-described or the descriptions available do not meet the standard description requirements defined by Clark *et al.* (1998).

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Table 1. List of Brachyuran species present in the WIO with description references.

List of Brachyuran species in the Western Indian Ocean

Family	Subfamily	Species	Zoeal description	Description reference
Cyclodorippidae	Cyclodorippinae	*Corycodus decorus* Tavares, 1993	No	
Cyclodorippidae	Cyclodorippinae	*Corycodus disjunctipes* (Stebbing, 1910)	No	
Cyclodorippidae	Cyclodorippinae	*Corycodus merweae* Tavares, 1993	No	
Cyclodorippidae	Xeinostomatinae	*Xeinostoma eucheir* Stebbing, 1920	No	
Cymonomidae		*Cymonomus mainbaza* Ahyong, 2014	No	
Cymonomidae		*Cymonomus trifurcus* Stebbing, 1920	No	
Cymonomidae		*Cymonomus valdivae* (Lankester, 1903)	No	
Dromiidae	Dromiinae	*Ascidiophilus caphyraeformis* Richters, 1880	No	
Dromiidae	Dromiinae	*Barnardromia bituberculata* (Stebbing, 1920)	No	
Dromiidae	Dromiinae	*Barnardromia hirsutimana* (Kensley & Buxton, 1984)	No	
Dromiidae	Dromiinae	*Conchoecetes artificiosus* (Fabricius, 1798)	Yes	McLay *et al.* (2001)
Dromiidae	Dromiinae	*Cryptodromia bullifera* (Alcock, 1900)	No	
Dromiidae	Dromiinae	*Cryptodromia fallax* (Latreille in Milberts, 1812)	No	
Dromiidae	Dromiinae	*Dromia dormia* (Linnaeus, 1763)	No	
Dromiidae	Dromiinae	*Dromidia aegibotus* Barnard, 1946	No	
Dromiidae	Dromiinae	*Dromidia cornuta* (Barnard, 1946)	No	
Dromiidae	Dromiinae	*Dromidia dissothrix* Barnard, 1946	No	
Dromiidae	Dromiinae	*Dromidia hirsutissima* Lamarck, 1818	No	
Dromiidae	Dromiinae	*Dromidia lepidota* (Barnard, 1946)	No	
Dromiidae	Dromiinae	*Eudromidia frontalis* (Henderson, 1888)	No	
Dromiidae	Dromiinae	*Eudromidia hendersoni* (Stebbing, 1921)	No	
Dromiidae	Dromiinae	*Exodromidia spinosa (Studer, 1883)*	No	
Dromiidae	Dromiinae	*Exodromidia spinosissima* (Kensley, 1977)	No	
Dromiidae	Dromiinae	*Hemisphaerodromia monodous* (Stebbing, 1918)	No	
Dromiidae	Dromiinae	*Lauridromia dehaani* (Rathbun, 1923)	Yes	McLay *et al.* (2001)

List of Brachyuran species in the Western Indian Ocean				
Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Dromiidae	Dromiinae	*Lauridromia intermedia* (Laurie, 1906)	No	
Dromiidae	Dromiinae	*Lewindromia unidentata* (Rüppell, 1830)	No	
Dromiidae	Dromiinae	*Metadromia wilsoni* (Fulton & Grant, 1902)	No	
Dromiidae	Dromiinae	*Platydromia spongiosa* (Stimpson, 1858)	No	
Dromiidae	Dromiinae	*Pseudodromia cacuminis* Kensley, 1980	No	
Dromiidae	Dromiinae	*Pseudodromia latens* Stimpson, 1858	No	
Dromiidae	Dromiinae	*Pseudodromia rotunda* (MacLeay, 1838)	No	
Dromiidae	Dromiinae	*Pseudodromia trepida* Kensley, 1978	No	
Dromiidae	Dromiinae	*Speodromia platyarthrodes* (Stebbing,1905)	No	
Dromiidae	Dromiinae	*Tumidodromia dormia* (Linnaeus,1763)	No	
Dynomenidae		*Dynomene pilumnoides* Alcock, 1900	No	
Homolodromiidae		*Homolodromia bouvieri* Doflein, 1904	No	
Homolidae		*Homola barbata* (Fabricius, 1793)	Yes	Rice & Provenzano (1970)
Homolidae		*Homola orientalis* Henderson, 1888	No	
Homolidae		*Homolochunia valdiviae* Doflein, 1904	No	
Homolidae		*Ihlopsis multispinosa* (Ihle, 1912)	No	
Homolidae		*Lamoha murotoensis* (Sakai, 1979)	No	
Homolidae		*Latreillopsis bispinosa* Henderson, 1888	No	
Homolidae		*Latreillopsis tetraspinosa* Dai & Chen, 1980	No	
Homolidae		*Moloha alcocki* (Stebbing, 1920)	No	
Homolidae		*Moloha alisae* Guinot & Richer de Forges, 1995	No	
Homolidae		*Paromola cuvieri* (Risso, 1816)	Yes	Samuelsen (1976)
Latreilliidae		*Eplumula phalangium* (De Haan, 1839)	No	
Latreilliidae		*Latreillia metanesa* Williams, 1982	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Latreilliidae		*Latreillia pennifera* Alcock, 1900	No	
Latreilliidae		*Latreillia valida* De Haan, 1839	No	
Raninidae	Lyreidinae	*Lyreidus brevifrons* Sakai, 1937	No	
Raninidae	Notopodinae	*Cosmonotus grayii* Adams in Belcher, 1848	No	
Raninidae	Notopodinae	*Notopus dorsipes* (Linnaeus, 1758)	No	
Raninidae	Ranininae	*Ranina ranina* (Linnaeus, 1758)	Yes	Sakai (1971)
Raninidae	Raninoidinae	*Raninoides barnardi* Sakai, 1974	No	
Aethridae		*Actaeomorpha erosa* Miers, 1877	No	
Aethridae		*Aethra scruposa* (Linnaeus, 1764)	No	
Aethridae		*Aethra seychellensis* Takeda, 1975	No	
Calappidae		*Calappa africana* Lai & Ng, 2006	No	
Calappidae		*Calappa gallus* (Herbst, 1803)	Yes	Taishaku & Konishi (1995)
Calappidae		*Calappa guerini* Brito Capello, 1871	No	
Calappidae		*Calappa hepatica* (Linnaeus, 1758)	No	
Calappidae		*Calappa japonica* Ortmann, 1892	Yes	Seridji (1993); Taishaku & Konishi (1995)
Calappidae		*Calappa lophos* (Herbst, 1782)	Yes	Taishaku & Konishi (1995)
Calappidae		*Calappa pustulosa* Alcock, 1896	No	
Calappidae		*Calappa woodmasoni* Alcock, 1896	No	
Calappidae		*Mursia africana* Galil, 1993	No	
Calappidae		*Mursia armata* de Haan, 1837	No	
Calappidae		*Mursia cristiata* H. Milne-Edwards, 1837	No	
Calappidae		*Mursia flamma* Galil, 1993	No	
Matutidae		*Ashtoret lunaris* (Forskål, 1775)	Yes	Seridji (1993); Taishaku & Konishi (1995)
Atelecyclidae		*Atelecyclus rotundatus* (Olivi, 1792)	Yes	Hong & Ingle (1987)
Cancridae		*Platepistoma seani* Davie & Ng, 2012	No	
Carpiliidae		*Carpilius convexus* (Forskål, 1775)	Yes	
Carpiliidae		*Carpilius maculatus* (Linnaeus, 1758)	Yes	Clark *et al.* (2005)

Corystidae		*Gomeza bicornis* Gray 1831	No	

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Family	Subfamily	Species	Zoeal description	Description reference
Dairidae		*Daira perlata* (Herbst, 1790)	No	
Dorippidae		*Dorippe frascone* (Herbst, 1785)	Yes	Quintana (1987)
Dorippidae		*Dorippe quadridens* (Fabricius, 1793)	No	
Dorippidae		*Dorippoides nudipes* Manning & Holthuis, 1986	No	
Dorippidae		*Medorippe lanata* (Linnaeus, 1767)	Yes	Paula (1991)
Ethusidae		*Ethusa machaera* Castro, 2005	No	
Ethusidae		*Ethusa sinespina* Kensley, 1969	No	
Ethusidae		*Ethusa zurstrasseni* Doflein, 1969	No	
Ethusidae		*Ethusina challengeri* (Miers, 1886)	No	
Ethusidae		*Ethusina longipes* Chen, 1987	No	
Ethusidae		*Ethusina somalica* (Doflein, 1904)	No	
Dairoididae		*Dairoides kusei* (Sakai, 1938)	No	
Dairoididae		*Dairoides margaritatus* Stebbing, 1920	No	
Eriphiidae		*Eriphia scabricula* Dana, 1852	Yes	Clark & Paula (2003)
Eriphiidae		*Eriphia sebana* (Shaw & Nodder, 1803)	Yes	Ko (2005)
Eriphiidae		*Eriphia smithii* MacLeay, 1838	Yes	Ko (2005)
Menippidae		*Menippe rumphii* (Fabricius, 1798)	No	
Menippidae		*Myomenippe fornasinii* (Bianconi, 1851)	No	
Menippidae		*Sphaerozius nitidus* Stimpson, 1858	Yes	Ko (2005)
Oziidae		*Epixanthus dentatus* (White, 1848)	Yes	Clark & Paula (2003)
Oziidae		*Epixanthus frontalis* (H.Milne-Edwards, 1834)	Yes	Al-Aidaroos, Al-Haj & Kumar (2014); Clark & Paula (2003)
Oziidae		*Lydia annulipes* (H. Milne-Edwards, 1834)	Yes	Clark & Paula (2003)
Oziidae		*Ozius rugulosus* Stimpson, 1858	Yes	Kakati & Nayak (1977)
Acidopsidae	Acidopsinae	*Parapilumnus pisifer* (MacLeay, 1838)	No	
Acidopsidae	Raouliinae	*Caecopilumnus piroculatus* (Rathburn, 1911)	No	
Chasmocarcinidae	Chasmocarcininae	*Camatopsis rubida* Alcock & Anderson, 1899	No	

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Family	Subfamily	Species	Zoeal description	Description reference
Euryplacidae		*Eucrate sulcatifrons* (Stimpson, 1858)	No	
Goneplacidae	Goneplacinae	*Carcinoplax ischurodous* (Stebbing, 1923)	No	
Goneplacidae	Goneplacinae	*Carcinoplax longimanus* (de Haan, 1833)	Yes	Terada (1984)
Goneplacidae	Goneplacinae	*Entricoplax vestita* (de Haan, 1835)	No	
Goneplacidae	Goneplacinae	*Goneplax clevai* Guinot & Castro, 2007	No	
Goneplacidae	Goneplacinae	*Goneplax rhomboides* (Linnaeus, 1758)	Yes	Ingle & Clark (1983)
Goneplacidae	Goneplacinae	*Ommatocarcinus pulcher* Barnard, 1950	No	
Goneplacidae	Goneplacinae	*Psopheticus crosnieri* Guinot, 1990	No	
Goneplacidae	Goneplacinae	*Psopheticus stridulans* Wood-Mason, 1892	No	
Goneplacidae	Goneplacinae	*Pycnoplax coryphaea* Castro, 2012	No	
Mathildellidae		*Beuroisia duhameli* Guinot & Richer de Forges, 1981	No	
Mathildellidae		*Neopilumnoplax heterochir* (Studer, 1883)	No	
Hexapodidae		*Hexapus stebbingi* Barnard, 1947	No	
Hexapodidae		*Spiroplax spiralis* (Barnard, 1950)	Yes	Lago (1988)
Leucosiidae	Cryptocneminae	*Cryptocnemus holdsworthi* Miers, 1877	No	
Leucosiidae	Cryptocneminae	*Leucisca squalina* (MacLeay, 1838)	No	
Leucosiidae	Ebaliinae	*Afrophila punctata* (Bell, 1855)	No	
Leucosiidae	Ebaliinae	*Arcania cornuta* (MacGilchrist,1905)	No	
Leucosiidae	Ebaliinae	*Arcania septemspinosa* (Fabricius, 1787)	Yes	Ko (2000)
Leucosiidae	Ebaliinae	*Arcania undecimspinosa* de Haan, 1841	Yes	Ko (2000)
Leucosiidae	Ebaliinae	*Ebalia agglomus* Barnard, 1955	No	
Leucosiidae	Ebaliinae	*Ebalia barnardi* Stebbing, 1914	No	
Leucosiidae	Ebaliinae	*Ebalia glomus* Stebbing, 1921	No	
Leucosiidae	Ebaliinae	*Ebalia pondoensis* Barnard, 1955	No	
Leucosiidae	Ebaliinae	*Ebalia tuberculata* Miers, 1881	No	
Leucosiidae	Ebaliinae	*Ebalia tuberculosa* (A. Milne-Edwards, 1873)	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Leucosiidae	Ebaliinae	*Heteronucia angulata* Barnard, 1946	No	
Leucosiidae	Ebaliinae	*Hiplyra michellinae* Galil, 2009	No	
Leucosiidae	Ebaliinae	*Hiplyra platycheir* (de Haan, 1841)	Yes	Ko (2000)
Leucosiidae	Ebaliinae	*Lithadia barnardi* Stebbing, 1920	No	
Leucosiidae	Ebaliinae	*Lyphira natalensis* Galil, 2009	No	
Leucosiidae	Ebaliinae	*Myra fugax* (Fabricius, 1798)	Yes	Ko (2000)
Leucosiidae	Ebaliinae	*Myra subgranulata* Kossman, 1877	No	
Leucosiidae	Ebaliinae	*Nucia speciosa* Dana, 1852	No	
Leucosiidae	Ebaliinae	*Nursilia dentata* Bell, 1855	No	
Leucosiidae	Ebaliinae	*Philyra globus* (Fabricius, 1775)	Yes	Krishnan & Kannupandi (1990)
Leucosiidae	Ebaliinae	*Philyra samia* Galil, 2009	No	
Leucosiidae	Ebaliinae	*Philyra scabriuscula* (Fabricius, 1798)	Yes	Rajabi (1960)
Leucosiidae	Ebaliinae	*Ryphila cancellus* Galil, 2009	No	
Leucosiidae	Ebaliinae	*Tanaoa pustulosus* (Wood-Mason in Wood-Mason & Alcock, 1891)	No	
Leucosiidae	Leucosiinae	*Soceulia marmorea* (Bell, 1855)	No	
Leucosiidae	Leucosiinae	*Urnalana whitei* (Bell, 1955)	No	
Epialtidae	Epialtinae	*Acanthonyx dentatus* H. Milne-Edwards, 1834	No	
Epialtidae	Epialtinae	*Acanthonyx quadridentatus* Krauss, 1843	No	
Epialtidae	Epialtinae	*Acanthonyx scutellatus* MacLeay, 1838	No	
Epialtidae	Epialtinae	*Acanthonyx undulatus* Barnard, 1947	No	
Epialtidae	Epialtinae	*Antilibinia smithii* MacLeay, 1838	No	
Epialtidae	Epialtinae	*Huenia heraldica* (de Haan, 1837)	Yes	Colavite *et al.* (2014)
Epialtidae	Epialtinae	*Menaethiops delagoae* Barnard, 1955	No	
Epialtidae	Epialtinae	*Menaethiops fascicularis* (Krauss, 1843)	No	
Epialtidae	Epialtinae	*Menaethiops natalensis* Barnard, 1955	No	
Epialtidae	Epialtinae	*Menaethius monoceros* (Latreille, 1825)	Yes	Colavite *et al.* (2014)
Epialtidae	Epialtinae	*Xenocarcinus tuberculatus* White, 1847	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Epialtidae	Pisinae	*Cyphocarcinus capreolus* (Paul'son,1875)	No	
Epialtidae	Pisinae	*Doclea muricata* (Herbst, 1788)	Yes	Krishnan & Kannupandi (1987)
Epialtidae	Pisinae	*Hyastenus convexus* Miers, 1884	No	
Epialtidae	Pisinae	*Hyastenus diacanthus* (de Haan, 1839)	No	
Epialtidae	Pisinae	*Hyastenus spinosus* A. Milne-Edwards, 1872	No	
Epialtidae	Pisinae	*Hyastenus uncifer* Calman, 1900	No	
Epialtidae	Pisinae	*Naxioides hirtus* A. Milne-Edwards, 1865	No	
Epialtidae	Pisinae	*Rochinia natalensis* Kensley, 1977	No	
Epialtidae	Pisinae	*Rochinia pulchra* (Miers, 1886)	No	
Epialtidae	Pisinae	*Tiarinia cornigera* (Latreille, 1825)	No	
Epialtidae	Tychinae	*Stilbognathus cervicornis* (Herbst, 1803)	No	
Inachidae		*Achaeopsis spinulosa* Stimpson,1857	No	
Inachidae		*Achaeus barnardi* Griffin, 1968	No	
Inachidae		*Achaeus curvirostris* (A. Milne-Edwards, 1873)	No	
Inachidae		*Achaeus lacertosus* Stimpson, 1858	No	
Inachidae		*Achaeus laevioculis* Miers, 1884	No	
Inachidae		*Achaeus spinossisimus* Griffin, 1968	No	
Inachidae		*Camposcia retusa* (Latreille, 1829)	No	
Inachidae		*Chorinachus dolichorhynchus* (Alcock & Anderson, 1894)	No	
Inachidae		*Cyrtomaia murrayi* Miers, 1885	No	
Inachidae		*Dorhynchus thomsoni* Thomson, 1873	Yes	Williamson (1982)
Inachidae		*Inachus dorsettensis* (Pennant, 1777)	Yes	Lebour (1927); Ingle (1977)
Inachidae		*Inachus guentheri* (Miers, 1879)	No	
Inachidae		*Macropodia falcifera* (Stimpson, 1858)	No	
Inachidae		*Macropodia formosa* Rathbun, 1911	No	
Inachidae		*Macropodia intermedia* Bouvier, 1940	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Inachidae		*Macropodia rostrata* (Linnaeus, 1761)	Yes	Ingle (1982)
Inachidae		*Oncinopus neptunus* Adams & White, 1848	No	
Inachidae		*Paratymolus barnardi* Loh & Ng, 1999	No	
Inachidae		*Paratymolus pubescens* Miers, 1879	No	
Inachidae		*Platymaia alcocki* Rathbun, 1918	No	
Inachidae		*Platymaia turbynei* Stebbing, 1902	No	
Inachidae		*Sunipea indicus* (Alcock, 1895)	No	
Majidae	Majinae	*Choniognathus elegans* (Stebbing, 1921)	No	
Majidae	Majinae	*Entomonyx spinosus* Miers, 1884	No	
Majidae	Majinae	*Eurynome aspera* (Pennant, 1777)	Yes	Salman (1982)
Majidae	Majinae	*Maja cornuta* (Linnaeus, 1758)	No	
Majidae	Majinae	*Maja squinado* (Herbst, 1788)	Yes	Lebour (1927); Guerao *et al*. (2008)
Majidae	Majinae	*Majella brevipes* Ortmann, 1893	No	
Majidae	Majinae	*Micippa philyra* (Herbst, 1803)	Yes	Ko (1995b)
Majidae	Majinae	*Micippa thalia* (Herbst, 1803)	Yes	Gore *et al*. (1982)
Majidae	Majinae	*Prismatopus longispinus* (de Haan, 1839)	No	
Majidae	Majinae	*Prismatopus tosaensis* (Sakai, 1969)	No	
Majidae	Majinae	*Sakaija africana* (Griffin & Tranter, 1986)	No	
Majidae	Majinae	*Schizophrys aspera* (H. Milne-Edwards, 1834)	Yes	Ghory (2012)
Oregoniidae	Pleistacanthinae	*Pleistacantha moseleyi* (Miers, 1886)	No	
Oregoniidae	Pleistacanthinae	*Pleistacantha ori* Ahyong & Ng, 2007	No	
Oregoniidae	Pleistacanthinae	*Pleistacantha oryx* Ortmann, 1893	No	
Palicidae		*Paliculus kyusyuensis* (Yokoya, 1933)	No	
Palicidae		*Parapalicus elaniticus* (Holthuis, 1977)	No	
Palicidae		*Pseudopalicus sexlobatus* (Kensley, 1969)	No	
Parthenopidae	Daldorfiinae	*Daldorfia horrida* (Linnaeus, 1758)	No	
Parthenopidae	Parthenopinae	*Enoplolambrus carenatus* (H. Milne-Edwards, 1834)	No	

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Parthenopidae	Parthenopinae	*Lambrachaeus ramifer* Alcock, 1895	No	
Pilumnidae	Eumodoninae	*Eumedonus niger* H. Milne-Edwards, 1834	No	
Pilumnidae	Eumodoninae	*Gonatonotus granulosus* (MacGilchrist, 1905)	No	
Pilumnidae	Pilumninae	*Actumnus setifer* (de Haan, 1835)	Yes	Clark & Ng (2004)
Pilumnidae	Pilumninae	*Benthopanope indica* (de Man, 1887)	Yes	Ko (1995a)
Pilumnidae	Pilumninae	*Eurycarcinus natalensis* (Krauss, 1843)	Yes	Clark & Paula (2003)
Pilumnidae	Pilumninae	*Pilumnus dofleini* Blass, 1933	No	
Pilumnidae	Pilumninae	*Pilumnus longicornis* Hilgendorf, 1878	Yes	Clark & Paula (2003)
Pilumnidae	Pilumninae	*Pilumnus minutus* de Haan, 1835	Yes	Ko (1994)
Pilumnidae	Pilumninae	*Pilumnus trichophoroides* de Man, 1895	No	
Pilumnidae	Pilumninae	*Pilumnus vespertilio* (Fabricius, 1793)	Yes	Lim & Tan (1979); Clark & Paula (2003)
Pilumnidae	Pilumninae	*Serenepilumnus pisifer* (MacLeay, 1838)	No	
Pilumnidae	Xenophthalmodinae	*Xenophthalmodes brachyphallus* Barnard, 1955	No	
Pilumnidae	Xenophthalmodinae	*Xenophthalmodes dolichophallus* Tesch, 1918	No	
Pilumnidae	Xenophthalmodinae	*Xenophthalmodes moebii* Richters, 1880	No	
Carcinidae	Carcininae	*Xaiva mcleayi* (Barnard, 1947)	No	
Geryonidae	Geryoninae	*Chaceon collettei* Manning, 1992	No	
Geryonidae	Geryoninae	*Chaceon macphersoni* (Manning & Holthuis, 1988)	No	
Ovalipidae		*Ovalipes iridescens* (Miers, 1885)	No	
Ovalipidae		*Ovalipes punctatus* (de Haan, 1833)	No	
Ovalipidae		*Ovalipes trimaculatus* (de Haan, 1833)	Yes	Schoeman & Cockroft (1996)
Polybiidae		*Parathranites orientalis* (Miers, 1886)	No	
Portunidae	Caphyrinae	*Caphyra alata* Richters, 1880	No	
Portunidae	Caphyrinae	*Caphyra unidentata* Lenz,1910	No	
Portunidae	Caphyrinae	*Coelocarcinus foliatus* Edmonson, 1930	No	
Portunidae	Caphyrinae	*Lissocarcinus laevis* Miers, 1886	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Portunidae	Caphyrinae	*Lissocarcinus orbicularis* Dana, 1852	No	
Portunidae	Carupinae	*Carupa tenuipes* Dana; 1852	No	
Portunidae	Lupocyclinae	*Lupocyclus tugelae* Barnard, 1950	No	
Portunidae	Podophthalminae	*Podophthalmus vigil* (Fabricius, 1798)	No	
Portunidae	Portuninae	*Carupella natalensis* Lenz & Strunck, 1914	No	
Portunidae	Portuninae	*Cycloachelous granulatus* (H. Milne-Edwards, 1834)	No	
Portunidae	Portuninae	*Cycloachelous orbicularis* (Richters, 1880)	No	
Portunidae	Portuninae	*Portunus argentatus* (A. Milne-Edwards, 1861)	No	
Portunidae	Portuninae	*Portunus gladiator* Fabricius, 1798	No	
Portunidae	Portuninae	*Portunus hastatoides* Fabricius, 1798	No	
Portunidae	Portuninae	*Portunus pelagicus* (Linnaeus, 1758)	Yes	Shinkarenko (1979); Josileen & Menon (2004)
Portunidae	Portuninae	*Portunus sanguinolentus* (Herbst, 1783)	Yes	Naidu (1955)
Portunidae	Portuninae	*Portunus segnis* (Forskål, 1775)	No	
Portunidae	Portuninae	*Scylla serrata* (Forskål, 1775)	Yes	Naidu (1955)
Portunidae	Thalamitinae	*Charybdis africana* Shen, 1935	No	
Portunidae	Thalamitinae	*Charybdis annulata* (Fabricius, 1798)	Yes	Islam *et al.* (2000)
Portunidae	Thalamitinae	*Charybdis feriata* (Linnaeus, 1758)	Yes	Motoh & Villaluz (1976); Fielder *et al.* (1984)
Portunidae	Thalamitinae	*Charybdis hellerii* (A. Milne-Edwards, 1867)	Yes	Dineen *et al.* (2001)
Portunidae	Thalamitinae	*Charybdis natator* (Herbst, 1794)	Yes	Islam *et al.* (2000)
Portunidae	Thalamitinae	*Charybdis orientalis* Dana, 1852	Yes	Islam *et al.* (2000)
Portunidae	Thalamitinae	*Charybdis smithii* MacLeay, 1838	No	
Portunidae	Thalamitinae	*Charybdis variegata* (Fabricius, 1798)	Yes	Islam *et al.* (2000)
Portunidae	Thalamitinae	*Thalamita admete* (Herbst, 1803)	No	
Portunidae	Thalamitinae	*Thalamita bevisi* (Stebbing, 1921)	No	
Portunidae	Thalamitinae	*Thalamita bouvieri* Nobili, 1906	No	
Portunidae	Thalamitinae	*Thalamita crenata* Rüppell, 1830	Yes	Krishnan & Kannupandi (1990a)

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Family	Subfamily	Species	Zoeal description	Description reference
Portunidae	Thalamitinae	*Thalamita danae* Stimpson, 1858	Yes	Krishnan & Kannupandi (1988b)
Portunidae	Thalamitinae	*Thalamita delagoae* Barnard, 1950	No	
Portunidae	Thalamitinae	*Thalamita helleri* Hoffmann, 1874	No	
Portunidae	Thalamitinae	*Thalamita integra integra* Dana, 1852	No	
Portunidae	Thalamitinae	*Thalamita picta* Stimpson, 1858	No	
Portunidae	Thalamitinae	*Thalamita prymna* (Herbst, 1803)	No	
Portunidae	Thalamitinae	*Thalamita sima* H.Milne-Edwards, 1834	No	
Portunidae	Thalamitinae	*Thalamita woodmasoni* Alcock, 1899	No	
Pseudoziidae		*Pseudozius caystrus* (Adams & White, 1849)	No	
Retroplumidae		*Retropluma planiforma* Kensley, 1969	No	
Tetraliidae		*Tetralia cinctipes* Paul'son, 1875	No	
Tetraliidae		*Tetralia glaberrima* (Herbst, 1790)	Yes	Clark & Galil (1988)
Tetraliidae		*Tetralia rubridactyla* Garth, 1971	Yes	Clark & Ng (2006)
Tetraliidae		*Tetraloides nigrifrons* (Dana, 1852)	No	
Trapeziidae	Quadrellinae	*Quadrella boopsis* Alcock, 1898	No	
Trapeziidae	Quadrellinae	*Quadrella coronata* Dana, 1852	No	
Trapeziidae	Quadrellinae	*Quadrella maculosa* Alcock, 1898	Yes	Clark & Ng (2006)
Trapeziidae	Quadrellinae	*Quadrella serenei* Galil, 1986	Yes	Clark & Ng (2006)
Trapeziidae	Trapeziinae	*Trapezia bidentata* (Forskål, 1775)	Yes	Al-Aidaroos (1992)
Trapeziidae	Trapeziinae	*Trapezia cymodoce* (Herbst, 1801)	Yes	Clark & Galil (1988)
Trapeziidae	Trapeziinae	*Trapezia digitalis* Latreille, 1828	Yes	Al-Aidaroos (1992)
Trapeziidae	Trapeziinae	*Trapezia guttata* Rüppell, 1830	No	
Trapeziidae	Trapeziinae	*Trapezia lutea* Castro, 1997	No	
Trapeziidae	Trapeziinae	*Trapezia richtersi* Galil & Lewinsohn, 1983	Yes	Clark & Ng (2006)
Trapeziidae	Trapeziinae	*Trapezia rufopunctata* (Herbst, 1799)	No	
Trapeziidae	Trapeziinae	*Trapezia speciosa* Dana, 1852	No	
Trichopeltariidae		*Trichopeltarion glaucus* (Alcock & Anderson, 1899)	No	
Panopeidae	Panopeinae	*Panopeus africanus* A. Milne-Edwards, 1867	Yes	Rodrígues & Paula (1993)

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Xanthidae	Actaeinae	*Actaea polyacantha* (Heller, 1861)	No	
Xanthidae	Actaeinae	*Actaea savignii* (H. Milne-Edwards, 1834)	No	
Xanthidae	Actaeinae	*Actaea spinosissima* Borradaile, 1902	No	
Xanthidae	Actaeinae	*Actaeodes hirsutissimus* (Rüppell, 1830)	Yes	Clark & Al-Aidaroos (1996)
Xanthidae	Actaeinae	*Actaeodes tomentosus* (H. Milne-Edwards, 1834)	Yes	Clark & Al-Aidaroos (1996)
Xanthidae	Actaeinae	*Epiactaea nodulosa* (White, 1848)	Yes	Clark (in press)
Xanthidae	Actaeinae	*Forestiana depressa* (White, 1848)	No	
Xanthidae	Actaeinae	*Gaillardiellus rueppelli* (Krauss, 1843)	No	
Xanthidae	Actaeinae	*Paractaea rebieri* Guinot, 1969	No	
Xanthidae	Actaeinae	*Paractaea rufopunctata* (H. Milne-Edwards, 1834)	No	
Xanthidae	Actaeinae	*Psaumis cavipes* (Dana, 1852)	Yes	Clark (in press)
Xanthidae	Actaeinae	*Pseudoliomera speciosa* (Dana, 1852)	Yes	Clark & Galil (1998)
Xanthidae	Actaeinae	*Pseudoliomera variolosa* (Borradaile, 1902)	No	
Xanthidae	Banareiinae	*Banareia parvula* (Krauss, 1843)	No	
Xanthidae	Chlorodiellinae	*Chlorodiella laevissima* (Dana, 1852)	No	
Xanthidae	Chlorodiellinae	*Chlorodiella nigra* (Forskål, 1775)	No	
Xanthidae	Chlorodiellinae	*Cyclodius obscurus* (Hombron & Jacquinot, 1846)	No	
Xanthidae	Chlorodiellinae	*Cyclodius ungulatus* (H. Milne Edwards, 1834)	No	
Xanthidae	Chlorodiellinae	*Luniella pugil* (Dana, 1852)	No	
Xanthidae	Chlorodiellinae	*Phymodius ungulatus* (H. Milne-Edwards, 1834)	No	
Xanthidae	Chlorodiellinae	*Pilodius areolatus* (H. Milne-Edwards, 1834)	No	
Xanthidae	Chlorodiellinae	*Pilodius melanospinis* (Rathbun, 1911)	No	
Xanthidae	Chlorodiellinae	*Pilodius pilumnoides* (White, 1848)	No	
Xanthidae	Cymoinae	*Cymo andreossyi* (Audouin, 1826)	Yes	Al-Haj *et al.* (2017)
Xanthidae	Cymoinae	*Cymo melanodactylus* Dana, 1852	Yes	Al-Haj *et al.* (2017); Clark (in press)
Xanthidae	Cymoinae	*Cymo quadrilobatus* Miers, 1884	Yes	Al-Haj *et al.* (2017)

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Xanthidae	Etisinae	*Etisus anaglyptus* H. Milne-Edwards, 1834	Yes	Al-Haj and Al-Aidaroos (2017); Clark (in press)
Xanthidae	Etisinae	*Etisus electra* (Herbst, 1801)	Yes	Al-Haj and Al-Aidaroos (2017)
Xanthidae	Etisinae	*Etisus laevimanus* Randall, 1840	Yes	Suzuki (1978)
Xanthidae	Euxanthinae	*Hypocolpus diverticulatus* (Strahl, 1861)	No	
Xanthidae	Euxanthinae	*Medaeops granulosus* (Haswell, 1882)	Yes	Clark (in press)
Xanthidae	Euxanthinae	*Medaeops neglectus* (Balss, 1922)	No	
Xanthidae	Euxanthinae	*Monodaeus tuberculidens* (Rathbun, 1911)	No	
Xanthidae	Kraussiinae	*Kraussia rugulosa* (Krauss, 1843)	No	
Xanthidae	Liomerinae	*Liomera bella* (Dana, 1852)	Yes	Yang & Ko (2005); Clark (in press)
Xanthidae	Liomerinae	*Liomera cinctimanus* (White, 1847)	Yes	Clark (in press)
Xanthidae	Liomerinae	*Liomera monticulosa* (A. Milne-Edwards, 1973)	No	
Xanthidae	Liomerinae	*Liomera rugata* (H. Milne Edwards, 1834)	No	
Xanthidae	Liomerinae	*Liomera stimpsonii* (A. Milne-Edwards, 1865)	No	
Xanthidae	Liomerinae	*Liomera tristis* (Dana, 1852)	No	
Xanthidae	Liomerinae	*Neoliomera sabaea* (Nobili, 1906)	No	
Xanthidae	Liomerinae	*Neoliomera themisto* (de Man, 1889)	No	
Xanthidae	Polydectinae	*Lybia leptochelis* (Zehntner, 1894)	No	
Xanthidae	Polydectinae	*Lybia plumosa* Barnard, 1946	Yes	Clark & Paula (2003)
Xanthidae	Polydectinae	*Lybia tessellata* (Latreille in Milbert, 1812)	No	
Xanthidae	Xanthinae	*Lachnopodus subacutus* (Stimpson, 1858)	Yes	Clark (in press)
Xanthidae	Xanthinae	*Leptodius exaratus* (H. Milne-Edwards, 1834)	Yes	Clark & Paula (2003); Al Aidaroos *et al.* (2017)
Xanthidae	Xanthinae	*Leptodius sanguineus* (H. Milne-Edwards, 1834)	Yes	Clark (in press)
Xanthidae	Xanthinae	*Macromedaeus quinquedentatus* (Krauss, 1843)	No	
Xanthidae	Xanthinae	*Macromedaeus voeltzkowi* (Lenz, 1905)	No	

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Xanthidae	Xanthinae	*Neoxanthias impressus* (Latreille in Milbert, 1812)	No	
Xanthidae	Xanthinae	*Xanthias lamarckii* (H.Milne-Edwards, 1834)	No	
Xanthidae	Xanthinae	*Xanthias maculatus* Sakai, 1961	No	
Xanthidae	Xanthinae	*Xanthias punctatus* (H. Milne-Edwards, 1934)	No	
Xanthidae	Zosiminae	*Atergatis floridus* (Linnaeus, 1767)	Yes	Tanaka & Konishi (2001)
Xanthidae	Zosiminae	*Atergatis granulatus* de Man, 1889	No	
Xanthidae	Zosiminae	*Atergatis ocyroe* (Herbst, 1801)	No	
Xanthidae	Zosiminae	*Atergatis roseus* (Rüppell, 1830)	No	
Xanthidae	Zosiminae	*Atergatopsis obesa* (A. Milne-Edwards, 1865)	No	
Xanthidae	Zosiminae	*Atergatopsis signata* (Adams & White, 1849)	No	
Xanthidae	Zosiminae	*Lophozozymus dodone* (Herbst, 1801)	No	
Xanthidae	Zosiminae	*Paratergatis longimanus* Sakai, 1965	No	
Xanthidae	Zosiminae	*Platypodia granulosa* (Rüppell, 1830)	No	
Xanthidae	Zosiminae	*Zosimus aeneus* (Linnaeus, 1758)	No	
Xanthidae	Zosiminae	*Zozymodes cavipes* (Dana, 1852)	No	
Xanthidae	Zosiminae	*Zozymodes xanthoides* (Krauss, 1843)	Yes	Clark & Paula (2003)
Cryptochiridae		*Cryptochirus coralliodytes* Heller, 1861	No	
Cryptochiridae		*Hapalocarcinus marsupialis* Stimpson, 1859	Yes	Gore *et al.* (1983)
Gecarcinidae		*Cardisoma carnifex* (Herbst, 1796)	Yes	Flores *et al.*(2003)
Grapsidae		*Geograpsus stormi* de Man, 1895	No	
Grapsidae		*Grapsus fourmanoiri* Crosnier, 1965	Yes	Flores *et al.* (2003)
Grapsidae		*Grapsus tenuicrustatus* (Herbst, 1783)	Yes	Flores *et al.* (2003)
Grapsidae		*Metopograpsus messor* (Forskål, 1775)	Yes	Flores *et al.* (2003)
Grapsidae		*Metopograpsus thukuhar* (Owen, 1839)	No	
Grapsidae		*Pachygrapsus minutus* A.Milne-Edwards, 1873	Yes	Flores *et al.* (2003)
Grapsidae		*Pachygrapsus plicatus* (H.Milne-Edwards, 1837)	Yes	Flores *et al.* (2003)

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Grapsidae		*Planes major* (MacLeay, 1838)	No	
Grapsidae		*Planes marinus* Rathbun, 1914	Yes	Wear (1970)
Grapsidae		*Planes minutus* (Linnaeus, 1758)	Yes	Cuesta *et al.* (1997)
Percnidae		*Percnon guinotae* Crosnier, 1965	No	
Percnidae		*Percnon planissimum* (Herbst, 1804)	No	
Plagusiidae		*Euchirograpsus polyodous* (Stebbing, 1921)	No	
Plagusiidae		*Guinusia chabrus* (Linnaeus, 1758)	Yes	Schubart & Cuesta (2010)
Plagusiidae		*Miersiograpsus kingsleyi* (Miers, 1885)	No	
Plagusiidae		*Plagusia depressa* (Fabricius, 1775)	Yes	Wilson & Gore (1980)
Plagusiidae		*Plagusia squamosa* (Herbst, 1790)	No	
Sesarmidae		*Chiromantes eulimene* (de Man, 1897)	Yes	Pereyra Lago (1993b); Flores *et al*. (2003); Guerao *et al.* (2011)
Sesarmidae		*Chiromantes ortmanni* (Crosnier, 1965)	Yes	Guerao *et al.* (2012)
Sesarmidae		*Neosarmatium africanum* Ragionieri, Fratini & Schubart, 2012	No	
Sesarmidae		*Neosarmatium meinerti* (de Man, 1887)	Yes	Pereyra Lago (1989); Flores *et al.* (2003)
Sesarmidae		*Neosarmatium smithi* (H. Milne-Edwards, 1853)	No	
Sesarmidae		*Parasesarma catenatum* (Ortmann, 1897)	Yes	Pereyra Lago (1987); Flores *et al.* (2003)
Sesarmidae		*Parasesarma leptosoma* (Hilgendorf, 1869)	Yes	Flores *et al.* (2003)
Sesarmidae		*Parasesarma plicatum* (Latreille, 1803)	Yes	Selvakumar (1999)
Sesarmidae		*Perisesarma guttatum* (A. Milne-Edwards, 1869)	Yes	Pereyra Lago (1993a)
Sesarmidae		*Perisesarma samawati* Gillikin & Schubart, 2004	No	
Sesarmidae		*Sarmatium crassum* Dana, 1851	Yes	Flores *et al.* (2003)
Sesarmidae		*Selatium elongatum* (A. Milne-Edwards, 1869)	No	
Sesarmidae		*Sesarmoides longipes* (Krauss, 1843)	No	
Varunidae	Cyclograpsinae	*Cyclograpsus punctatus* H. Milne-Edwards, 1937	Yes	Fagetti & Campodonico (1971)

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Family	**Subfamily**	**Species**	**Zoeal description**	**Description reference**
Varunidae	Cyclograpsinae	*Parahelice balssi* (K. Sakai, Türkay & Yang, 2006)	No	
Varunidae	Cyclograpsinae	*Pseudohelice subquadrata* (Dana, 1851)	No	
Varunidae	Gaeticinae	*Brankocleistostoma fossulum* (Barnard, 1955)	No	
Varunidae	Varuninae	*Pseudograpsus elongatus* (A. Milne-Edwards, 1873)	No	
Varunidae	Varuninae	*Ptychognathus onyx* Alcock, 1900	No	
Varunidae	Varuninae	*Varuna litterata* (Fabricius, 1798)	No	
Camptandriidae		*Danielella edwardsii* (MacLeay, 1838)	No	
Camptandriidae		*Paratylodiplax algoensis* (Barnard, 1954)	No	
Camptandriidae		*Paratylodiplax blephariskios* (Stebbing, 1924)	No	
Dotillidae		*Dotilla fenestrata* Hilgendorf, 1869	Yes	Paula *et al.* (in prep.)
Dotillidae		*Lazarocleistostoma dentatum* (Tesch, 1918)	No	
Macrophthalmidae	Ilyograpsinae	*Ilyograpsus paludicola* (Rathbun, 1909)	Yes	Flores *et al.* (2003)
Macrophthalmidae	Ilyograpsinae	*Ilyograpsus rhizophorae* Barnard, 1955	No	
Macrophthalmidae	Macrophthalminae	*Chaenostoma boscii* (Audouin, 1826)	Yes	Paula *et al.* (in prep.)
Macrophthalmidae	Macrophthalminae	*Chaenostoma sinuspersici* (Naderloo & Türkay, 2011)	No	
Macrophthalmidae	Macrophthalminae	*Macrophthalmus convexus* Stimpson, 1858	No	
Macrophthalmidae	Macrophthalminae	*Macrophthalmus depressus* Stimpson, 1859	Yes	Paula *et al.* (in prep.)
Macrophthalmidae	Macrophthalminae	*Macrophthalmus grandidieri* A. Milne-Edwards, 1867	Yes	Paula *et al.* (in prep.)
Macrophthalmidae	Macrophthalminae	*Venitus latreillei* (Desmarest, 1822)	Yes	Selvakumar *et al.* (1988)
Ocypodidae	Gelasiminae	*Astruca annulipes* (H. Milne-Edwards, 1837)	Yes	Paula *et al.* (in prep.)
Ocypodidae	Gelasiminae	*Cranuca inversa* (Hoffman, 1874)	No	
Ocypodidae	Gelasiminae	*Gelasimus hesperiae* Crane, 1975	No	
Ocypodidae	Gelasiminae	*Gelasimus vocans* (Linnaeus, 1758)	Yes	Paula *et al.* (in prep.)
Ocypodidae	Gelasiminae	*Paraleptuca chlorophthalmus* (H. Milne Edwards, 1837)	Yes	Paula *et al.* (in prep.)

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Family	Subfamily	Species	Zoeal description	Description reference
Ocypodidae	Gelasiminae	*Paraleptuca crassipes* (White, 1847)	No	
Ocypodidae	Gelasiminae	*Tubuca urvillei* (H. Milne-Edwards, 1852)	Yes	Paula *et al*. (in prep.)
Ocypodidae	Ocypodinae	*Ocypode ceratophthalmus* (Pallas, 1772)	Yes	Jiang *et al.* (2014)
Ocypodidae	Ocypodinae	*Ocypode cordimana* Latreille, 1818	Yes	Jiang *et al.* (2014)
Ocypodidae	Ocypodinae	*Ocypode madagascariensis* Crosnier, 1965	No	
Ocypodidae	Ocypodinae	*Ocypode ryderi* Kingsley, 1880	No	
Pinnotheridae	Pinnothereliinae	*Pinnixa penultipedalis* Stimpson, 1859	No	
Pinnotheridae	Pinnotherinae	*Ostracotheres tridacnae* (Rüppell, 1830)	No	
Pinnotheridae	Pinnotherinae	*Pinnotheres dofleini* Lenz, 1915	No	
Pinnotheridae	Pinnotherinae	*Pinnotheres globosus* Hombron & Jacquinot, 1847	No	
Pinnotheridae	Pinnotherinae	*Xanthasia murigera* White, 1847	No	
Hymenosomatidae	Hymenosomatinae	*Elamena mathoei* (Desmarest, 1823)	Yes	Krishnan & Kannupandi (1988a)
Hymenosomatidae	Hymenosomatinae	*Halicarcinus planatus* (Fabricius, 1775)	Yes	Boschi *et al.*(1969)
Hymenosomatidae	Hymenosomatinae	*Hymenosoma geometricum* Stimpson, 1858	No	
Hymenosomatidae	Hymenosomatinae	*Hymenosoma orbiculare* Desmarest, 1823	Yes	Dornelas *et al.* (2003)
Hymenosomatidae	Hymenosomatinae	*Neorhynchoplax bovis* (Barnard, 1946)	No	
Hymenosomatidae	Hymenosomatinae	*Trigonoplax unguiformis* (de Haan, 1839)	Yes	Dornelas *et al.* (2003)

References

Al-Aidaroos AM (1992) The first zoeal stage of four species of *Trapezia* (Crustacea, Brachyura, Xanthidae). Marine Sciences 3 (1): 57-66

Al-Aidaroos AM, Al-Haj AE, Kumar AAJ (2014) Complete larval development of the Brachyuran crab (*Epixanthus frontalis* H. Milne Edwards, 1834) (Crustacea, Decapoda, Eriphioidea, Oziidae) under laboratory conditions. Zootaxa 3815 (1): 29-50 [doi: 10.11646/zootaxa.3815.1.2.]

Al-Aidaroos AM, Kumar AAJ, Al-Haj AE (2017) Redescription of the larval stages of *Leptodius exaratus* (H. Milne Edwards, 1834) from the Red Sea, with notes on the male gonopods. Marine Biodiversity 47 (4): 1171-1184 [doi: 10.1007/s12526-017-0692-5.]

Al-Haj AE, Al-Aidaroos AM (2017) Descriptions of the first stages of four species of *Etisus* (Brachyura, Xanthoidea, Etisinae) reared from the central Red Sea, Saudi Arabia. Marine Biodiversity 47 (4): 1185-1191 [doi: 10.1007/s12526-017-0644-0.]

Al-Haj AE, Al-Aidaroos AM, Kumar AAJ (2017) Description of the larval stages of the Red Sea-inhabiting *Cymo melanodactylus* de Haan, 1833, *C. andreossyi* (Audouin, 1826) and *C. quadrilobatus* Miers, 1884 (Decapoda: Brachyura:Xanthidae:Cymoinae) reared under laboratory conditions. Marine Biodiversity 47 (4): 1193-1207 [doi: 10.1007/s12526-017-0777-1.]

Barnard KH (1950) Descriptive catalogue of South African decapod Crustacea. *Annals of the South African Museum* 38: 1-837

Boschi EE, Scelzo MA, Goldstein B (1969) Desarrollo larval del cangrejo *Halicarcinus planatus* (Fabricius) (Crustacea, Decapoda, Hymenosoidae), en el laboratorio, con observaciones sobre la distribuicion de la especie. Bulletin of Marine Science 19 (1): 225-242

Busulini A, Tessier G, Beschin C (2006) The genus *Phlyctenodes* Milne Edwards, 1862 (Crustacea: Decapoda: Xanthidae) in the Eocene of Europe. Revista Mexicana de Ciencias Geologicas 23 (3): 350-360

Castro P (1997) Trapeziid crabs (Brachyura: Xanthoidea: Traeziidae) of New Caledonia, Eastern Australia, and the Coral Sea. In: Richer de Forges B (ed) Les fonds meubles des lagons de Nouvelle-CalMonie (Sédimentologie, Benthos) *Études & Thèses*, Volume 3, ORSTOM, Paris, pp 59-107

Clark PF, Galil BS (1988) Redescriptions of *Tetralia cavimana* Heller, 1861 and *Trapezia cymodoce* (Herbst, 1799) first stage zoeas with implications for classification within the superfamily Xanthoidea (Crustacea: Brachyura). Proceedings of the Biological Society of Washington 101 (4): 853-860

Clark PF, Al-Aidaroos AM (1996) The First Zoeas of *Actaeodes hirsutissimus* (Ruppell, 1830) and *A. tomentosus* (H. Milne Edwards, 1834)(Crustacea: Decapoda: Brachyura: Xanthidae: Actaeinae). Marine Sciences 17 (1): 207-214

Clark PF, Galil BS (1998) The first stage zoea of *Pseudoliomera speciosa*. Zoosystema 20 (2): 193-200

Clark PF, Calazans D, Pohle GW (1998) Accuracy and standardization of brachyuran larval descriptions. Invertebrate Reproduction and Development 33 (2-3): 127-144 [doi: 10.1080/07924259.1998.9652627.]

Clark PF, Paula J (2003) Descriptions of ten xanthoidean (Crustacea: Decapoda: Brachyura) first stage zoeas from Inhaca Island, Mozambique. Raffles Bulletin of Zoology 51 (2): 323-378

Clark PF, Ng PKL (2004) The larval development of *Actumnus setifer* (de Haan, 1835)(Brachyura: Xanthoidea: Pilumnidae) described from laboratory reared material. Crustacean Research 33: 27-50

Clark PF, Ng PKL, Noho H, Shokita S (2005) The first-stage zoeas of *Carpilius convexus* (Forskål, 1775) and *Carpilius maculatus* (Linnaeus, 1758) (Crustacea: Decapoda: Brachyura: Xanthoidea: Carpiliidae): An example of heterochrony. Journal of Plankton Research 27 (2): 211-219 [doi: 10.1093/plankt/fbh169.]

Clark PF, Ng PKL (2006) First stage zoeas of *Quadrella* Dana, 1851 (Crustacea: Decapoda: Brachyura: Xanthoidea: Trapeziidae) and their affinities with those of *Tetralia* Dana, 1851, and *Trapezia* Latreille, 1828. Hydrobiologia 560 (1): 267-294 [doi: 10.1007/s10750-004-0636-5.]

Clark PF, Cuesta JA (2015) Larval systematics of Brachyura. In: Castro P, Davie PJF, Guinot D, Schram FR, von Vaupel Klein JC (eds) Treatise on Zoology - Anatomy, Taxonomy, Biology - The Crustacea, Volume 9, part C-II, Brill, pp 981-1048

Clark PF (in press) An atlas of selected Heterotremata (Crustacea: Brachyura: Eubrachyura) first stage zoeas

Colavite J, Santana W, Pohle GW (2014) Larval development of the spider crab *Menaethius monoceros* (Latreille, 1825), (Crustacea: Decapoda: Brachyura: Epialtidae). Journal of Natural History 48 (37-38): 2273-2292 [doi: 10.1080/00222933.2014.925596.]

Cuesta JA, González-Gordillo JI, Rodríguez A (1997) First zoeal stages of *Grapsus adscensionis* (Osbeck) and *Planes minutus* (Linnaeus) (Brachyura: Grapsidae) described from laboratory hatched material, with notes on larval characteres of the Grapsinae. Journal of Natural History 31: 887-900

Dineen JF, Clark PF, Hines AH, Reed SA, Walton HP (2001) Life history, larval description, and natural history of *Charybdis hellerii* (Decapoda, Brachyura, Portunidae), an invasive crab in the Western Atlantic. Journal of Crustacean Biology 21 (3): 774-805 [doi: 10.1043/0278-0372(2001)021(0774:lhldan)2.0.co;2.]

Dornelas M, Paula J, Macia A (2003) The larval development of *Hymenosoma orbiculare* Desmarest , 1825 (Crustacea: Decapoda: Brachyura: Hymenosomatidae). Journal of Natural History 37: 2579-2597

Emmerson WD (2016) A Guide to, and Checklist for, the Decapoda of Namibia, South Africa and Mozambique (Volumes 2 and 3). Cambridge Scholars Publishing

Fagetti E, Campodonico I (1971) The larval development of the crab *Cyclograpsus punctatus* H. Milne Edwards, under laboratory conditions (Decapoda Brachyura, Grapsidae, Sesarminae). Crustaceana, 21 (2): 183-195

Fielder DR, Greenwood JG, Campell G (1984) The megalopa of *Charybdis feriata* (Linnaeus) with additions to the zoeal larvae descriptions (Decapoda, Portunidae). Crustaceana 46 (2): 160-165 [doi: 10.1073/pnas.0703993104.]

Fischer W, Bianchi G, Scott WB (eds) (1981) Vol. 6: Shrimps and prawns, true crabs, stomatopods, bivalves, gastropods, cephalopods, sea turtles. In FAO species identification sheets for fishery purposes; Eastern Central Atlantic fishing areas 34, 47 (in part). Canada Funds-in-Trust. Ottawa, Department of Fisheries and Oceans Canada, by arrangement with the Food and Agriculture Organization of the United Nations

Flores AAV, Paula J, Dray T (2003) First zoeal stages of grapsoid crabs (Crustacea: Brachyura) from the East African coast. Zoological Journal of the Linnean Society 137 (3): 355-383 [doi: 10.1046/j.1096-3642.2003.00054.x.]

Ghory FS (2012) Description of the second zoeal stage of *Schizophrys aspera* (H. Milne Edwars, 1837) (Decapoda: Brachyrua: Majidae) collected from the Manora Channel, Karachi, Pakistan. FUUAST Journal of Biology 2 (2): 121-124

Gore RH, Scotto LE, Yang WT (1982) *Microphrys bicornutus* (Latreille, 1825): The complete larval development under laboratory conditions with notes on other Mithracine larvae (Decapoda: Brachyura: Majidae). Journal of Crustacean Biology 2 (4): 514-534

Gore RH, Scotto LE, Reed JK (1983) Early larval stages of the indo-pacific coral gall-forming crab *Hapalocarcinus marsupialis* Stimpson, 1859 (Brachyura, Hapalocarcinidae) cultured in the laboratory. Crustaceana 44 (2): 141-150

Guerao G, Pastor E, Martin J, Andrés M, Estévez A, Grau A, Duran J, Rotllant G (2008) The larval development of *Maja squinado* and *M. brachydactyla* (Decapoda, Brachyura, Majidae) described from plankton collected and laboratory-reared material. Journal of Natural History 42 (33-34): 2257-2276

Guerao G, Simoni R, Cannicci S, Anger K (2011) Morphological description of the megalopa and the first juvenile crab stage of *Chiromantes eulimene* (Decapoda, Brachyura, Sesarmidae), with a revision on zoeal morphology. Invertebrate Reproduction & Development 55 (2): 100-109 [doi: 10.1080/07924259.2011.553416.]

Guerao G, Anger K, Simoni R, Cannicci S (2012) The early life history of *Chiromantes ortmanni* (Crosnier, 1965) (Decapoda: Brachyura: Sesarmidae): morphology of larval and juvenile stages. Zootaxa 3347: 36-62

Hong SY, Ingle RW (1987) Larval development of the circular crab, *Atelecyclus rotundatus* (Olivi) (Crustacea: Brachyura: Atelecyclidae) reared in the laboratory. Journal of Natural History 21 (6): 1539-1560 [doi: 10.1080/00222938700770961.]

Ingle RW (1977) The larval and post-larval development of *Inachus dorsettensis* (Pennant) (Family: Majidae), reared in the laboratory. Bulletin of the British Museum (Natural History) 30: 331-342

Ingle RW (1982) Larval and post-larval development of the Slender-legged Spider Crab, *Macropodia rostrata* (Linnaeus) (Oxyrhyncha: Majidae: Inachinae), reared in the laboratory. Bulletin of the British Museum (Natural History) 42 (3): 207-225

Ingle RW, Clark PF (1983) The larval development of the angular crab, *Goneplax rhomboides* (Linnaeus) (Decapoda: Brachyura)', Bulletin of the British Museum (Natural History) 44 (2): 163-177

Islam S, Shokita S, Higa T (2000) Larval development of the swimming crab *Charybdis natator* (Crustacea: Brachyura: Portunidae) reared in the laboratory. Species Diversity 5: 329-349

Jiang G-C, Liu H-C, Chan T-Y, Chan BKK (2014) First stage zoeal morphology of four ghost crabs *Ocypode ceratophthalmus* (Pallas, 1772), *O. cordimanus* Latreille, 1818, *O. sinensis* Dai, Song & Yang, 1985 and *O. stimpsoni* Ortmann, 1897 (Crustacea, Decapoda, Ocypodidae). Zootaxa 3760 (3): 369-382

Johnsson R, Neves E, Franco GMO, Da Silveira FL (2006) The association of two gall crabs (Brachyura: Cryptochiridae) with the reef-building coral *Siderastrea stellata* Verrill, 1868. Hydrobiologia 559 (1): 379-384 [doi: 10.1007/s10750-005-9307-4.]

Josileen J, Menon NG (2004) Larval stages of the blue swimmer crab, *Portunus pelagicus* (Linnaeus, 1758) (Decapoda, Brachyura). Crustaceana 77 (7): 785-803

Kakati VS Nayak VN (1977) Larval development of the Xanthid crab , *Ozius rugulosus rugulosus* Stimpson (Decapoda, Brachyura) under laboratory conditions. Indian Journal of Marine Sciences 6: 26-30

Kensley B (1981) On the zoogeography of southern African decapod Crustacea, with a distributional checklist of the species. Smithsonian Contributions to Zoology 338: 1-64 [doi: 10.5479/si.00810282.338.]

Ko HS (1994) The zoeal stages of *Pilumnus minutus* De Haan, 1835 (Decapoda: Brachyura: Pilumnidae) in the laboratory. The Korean Journal of Systematic Zoology 10 (2): 145-155

Ko HS (1995a) Larval development of *Benthopanope indica* (de Man, 1887) (Decapoda: Brachyura: Pilumnidae) in the laboratory. Journal of Crustacean Biology 15 (2): 280-290 [doi: 10.1163/193724095X00280.]

Ko HS (1995b) Larval development of *Micippa philyra* (Herbst, 1803) reared in the laboratory (Decapoda, Brachyura, Majidae). Crustaceana 68 (7): 864-872

Ko HS (2000) Larval development of *Philyra platychira* (Decapoda: Leucosidae) reared in the laboratory. Journal of Crustacean Biology 20 (2): 309-319 [doi: 10.1651/0278-0372(2000)020[0309:LDOPPD]2.0.CO;2]

Ko HS (2005) First zoea of *Eriphia sebana* (Crustacea: Decapoda: Xanthoidea: Menippidae) hatched in the laboratory. Integrative Biosciences 9 (3): 135-138 [doi: 10.1080/17386357.2005.9647263]

Krishnan T, Kannupandi T (1987) Laboratory larval culture of a spider crab, *Doclea muricata* (Fabricius, 1787) (Decapoda, Majidae). Crustaceana 53 (3): 292-303. [http://www.tandfonline.com/doi/abs/10.1080/00222933.2014.925596.]

Krishnan T, Kannupandi T (1988a) Larval develpoment of *Elamena (Trigonoplax) cimex* Kemp, 1915 in the laboratory: the most unusal larvae known in the Brachyura (Crustacea: Decapoda). Bulletin of Marine Science 43 (2): 215-228

Krishnan T, Kannupandi T (1988b) Morphology of the larvae and first crab of an edible estuarine crab, *Thalamita danae* Stimpson, 1858 (Portunidae) from Indian Waters. Indian Journal of Fisheries 35 (2): 118-120

Krishnan T, Kannupandi T (1990a) Laboratory cultured zoeae, megalopa and first crab of the estuarine crab *Thalamita crenata* (Latr.) A. Milne Edwards 1861 (Brachyura: Portunidae). Mahasagar 23 (2): 139-152

Krishnan T, Kannupandi T (1990b) Larval and post-larval development of the purse crab *Philyra globosa* (Fabricius, 1888) (Decapoda: Brachyura: Leucosiidae) reared in the laboratory. Hydrobiologia 190: 171-182

Lebour MV (1927) Studies of the Plymouth Brachyura. I. The rearing of crabs in captivity, with a description of the larval stages of *Inachus Dorsettensis*, *Macropodia longirostris* and *Maia squinado*. Journal of the Marine Biological Association of the United Kingdom 14 (3): 795-821

Lim SSL, Tan LWH (1979) Larval development of the hairy crab, *Pilumnus vespertilio* (Fabricius) (Brachyura, Xanthidae) in the laboratory and comparisons with larvae of *Pilumnus dasypodus* Kingsley and *Pilumnus sayi* Rathbun. Crustaceana 41 (1): 71-88

Marco-Herrero E, Torres AP, Cuesta JA, Guerao G, Palero F, Abello P (2013) The systematic position of Ergasticus (Decapoda, Brachyura) and allied genera, a molecular and morphological approach. Zoologica Scripta 42 (4): 427-439 [doi: 10.1111/zsc.12012]

McLay CL, Lim SSL, Ng PKL (2001) On the first zoea of Lauridromia indica (Gray, 1831), with an appraisal of the generic classification of the Dromiidae (Decapoda: Brachyura) using larval characters. Journal of Crustacean Biology 21 (3): 733-747 [doi: 10.1651/0278-0372(2001)021[0733:OTFZOL]2.0.CO;2]

Motoh H, Villaluz A (1976) The zoeal stages of a swimming crab, *Charybdis cruciata* (Herbst) reared in the laboratory. Bulletin of the Japanese Society of Scientific Fisheries 42 (5): 523-531 [doi: 10.5088/atl.2010.32.1.59]

Naidu KGRB (1955) The early development of *Scylla serrata* (Forskål, 1775) and *Neptunus sanguinolentus* (Herbst, 1783). Indian Journal of Fisheries 2: 67-76

Ng PKL, Guinot D, Davie PJF (2008) Systema Brachyurorum : Part I . an annotated checklist of extant brachyuran crabs of the world. The Raffles Bulletin of Zoology 17: 1-286

Paula J (1991) The zoeal stages of the crab *Medorippe lanata* (Linnaeus, 1767) (Brachyura, Dorippidae) reared in the laboratory, and the larval characters of the Dorippidae. Journal of Natural History 25: 75-89

Paula J, Mega Lopes P, Serbino NMB, Marques F (in prep.) Newly-hatched stages of ocypodid crabs (Brachyura: Ocypodidae) from Inhaca Island, Mozambique. Unpublished manuscript

Pereyra Lago R (1987) Larval development of *Sesarma catenata* Ortmann (Brachyura, Grapsidae, Sesarminae) reared in the laboratory. South African Journal of Zoology 22 (3): 200-212 [doi: 10.1080/02541858.1987.11448047]

Pereyra Lago R (1988) Larval development of *Spirolax spiralis* (Barnard, 1950) (Brachyura: Hexapodidae) in the laboratory; the systematic position of the family on the basis of larval morphology. Journal of Crustacean Biology 8 (4): 576-593

Pereyra Lago R (1989) The larval development of the red mangrove crab *Sesarma meinerti* de Man (Brachyura: Grapsidae) reared in the laboratory. South African Journal of Zoology 24 (3): 199-211 [doi: 10.1080/02541858.1989.11448153]

Pereyra Lago R (1993a) Larval development of *Sesarma guttatum* A. Milne Edwards (Decapoda: Brachyura: Grapsidae) reared in the laboratory, with comments on larval generic and familial characters. Journal of Crustacean Biology 13 (4): 745-762

Pereyra Lago R (1993b) The zoeal development of *Sesarma eulimene* de Man (Decapoda, Brachyura, Grapsidae), and identification of larvae of the genus *Sesarma* in South African waters. South African Journal of Zoology 28 (4): 173-181 [doi: 10.1080/02541858.1993.11448315]

Quintana R (1987) Later zoeal and early postlarval stages of three dorippid species from Japan (Brachyura: Dorippidae: Dorippinae). Publications of the Seto Marine Biological Laboratory 32 (4/6): 233-274

Rajabai KG (1960) Studies on the larval development of Brachyura II. Development of *Philyra scabriuscula* (Fabricius) and *Ixa cylindrus* (Fabricius) of the family Leucosiidae. Crustaceana 1 (1): 1-8

Rice AL (1980) Crab zoeal morphology and its bearing on the classification of the Brachyura. Transactions of the Zoological Society of London 35 (3): 271-424 [doi: 10.1111/j.1096-3642.1980.tb00060.x]

Rice AL, Hartnoll RG (1983) Aspects of the biology of the deep-sea spider crab, *Dorhyncus thomsoni* (Crustacea:Brachyura). Journal of Zoology 201 (3): 417-431 [doi: 10.1111/j.1469-7998.1983.tb04285.x]

Rice AL, Provenzano Jr AJ (1970) The larval stages of *Homola barbata* (Fabricius) (Crustacea, Decapoda, Homolidae) reared in the laboratory. Bulletin of Marine Science 20 (2): 446-471

Rodríguez A, Paula J (1993) Larval and postlarval development of the Mud Crab *Panopeus africanus* A.Milne-Edwards (Decapoda, Xanthidae) reared in the laboratory. Journal of Crustacean Biology 13 (2): 296-308

Sakai K (1971) The larval stages of *Ranina ranina* (Linnaeus) (Crustacea, Decapoda, Raninidae) reared in the laboratory, with a review of uncertain zoeal larvae attributed to *Ranina*. Publications of the Seto Marine Biological Laboratory 19 (2/3): 123-156

Salman SD (1982) Larval development of the spider crab *Eurynome aspera* (Pennant), reared in the laboratory, with a key to the subfamily Pisinae (Brachyura, Majidae). Crustaceana 43 (1): 78-88

Samuelsen TJ (1976) The first zoea of *Paromola cuvieri* (Risso) (Decapoda, Homolidae). Sarsia 62 (1): 5-8 [doi: 10.1080/00364827.1976.10411309]

Schoeman DS, Cockcroft AC (1996) A description of *Ovalipes trimaculatus* (De Haan, 1833) (Brachyura: Portunidae: Polybiinae) zoeae reared in the laboratory. South African Journal of Marine Science 17 (1): 113-134 [doi: 10.2989/025776196784158338]

Schubart CD, Cuesta JA (2010) Phylogenetic relationships of the Plagusiidae Dana, 1815, with description of a new genus and recognitions of Percnidae Stevcic, 2005. In: Ng P, Castro P, Davie P, Richer de Forges B (eds) Studies on Brachyura: a Homage to Danièle Guinot, Brill, pp 279-299

Schubart CD, Liu HC, Cuesta JA (2003) A new genus and species of tree-climbing crab (Crustacea: Brachyura: Sesarmidae) from Taiwan with notes on its ecology and larval morphology. Raffles Bulletin of Zoology 51 (1): 49-59

Selvakumar S (1999) The complete larval development of *Parasesarma plicatum* (Latreille, 1806) (Decapoda: Brachyura: Grapsidae) reared in the laboratory. The Raffles Bulletin of Zoology 47 (1): 237-250

Selvakumar S, Ajmalkhan S, Natarajan R (1988) Laboratory reared larval stages of ocypodid crab *Macropthalmus (Venitus) latreilli* (Desmarest). Mahasagar 21 (3): 161-172

Seridji R (1993) Descriptions of some planktonic larvae of the Calappidae (Crustacea: Decapoda; Brachyura). Journal of Plankton Research 15 (4): 437-453 [doi: 10.1093/plankt/15.4.437]

Shinkarenko L (1979) Development of the Larval stages of the blue swimming crab *Portunus pelagicus* L. (Portunidae: Decapoda: Crustacea). Australian Journal of Marine and Freshwater Research 30 (4): 485-503 [doi: 10.1071/MF9790485]

Suzuki H (1978) The larval development of *Etisus laevimanus* Randall (Crustacea, Brachyura, Xanthidae). Le mer (Bulletin de la Société franco-japonaise d'océnographie) 16 (4): 176-187

Taishaku H, Konishi K (1995) Zoeas of *Calappa* species with special reference to larval characters of the family Calappidae (Crustacea, Brachyura). Zoological Science 12 (5): 649-654

Tanaka H, Konishi K (2001) Larval development of the poisonous crab *Atergatis floridus* (Linnaeus, 1767) (Crustacea, Decapoda, Xanthidae) described from laboratory-reared material. Crustacean Research 30: 21-42

Terada M (1984) Comparison of zoeal deyelopment between the two carcinoplacid crabs, *Carcinoplax logimana* (De Haan) and *Eucrate crenata* De Haan, reared in laboratory. Zoological Society of Japan 1: 743-750

Wear RG (1970) Life-history studies on New Zealand Brachyura. New Zealand Journal of Marine and Freshwater Research 4 (1): 3-35 [doi: 10.1080/00288330.1970.9515324]

Williamson DI (1982) The larval characters of *Dorhynchus thomsoni* Thomson (Crustacea, Brachyura, Majoidea) and their evolution. Journal of Natural History 16: 727-744

Wilson KA, Gore RH (1980) Studies on Decapod Crustacea from the Indian River Region of Florida, XVII. Larval stages of *Plagusia depressa* (Fabricius, 1775) cultured under laboratory conditions (Brachyura: Grapsidae). Bulletin of Marine Science 30 (4): 776-789

Yang HJ, Ko HS (2005) First zoea of *Liomera bella* (Crustacea: Decapoda: Xanthidae) reared in the laboratory. The Korean Journal of Systematic Zoology 21 (2): 193-199

Navigating the sea space: the nature and significance of giriama indigenous knowledge on marine resources

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Abstract

This paper presents the findings of a study on indigenous knowledge and management systems of marine resources among the Giriama people of the Kenyan north coast and their intimate relationship with their environment, especially marine resources. The product of this relationship is a profound knowledge of the resources dependent on indigenous ecological knowledge of marine resources. This knowledge is distributed in the community based on age, gender and professional affinity to the resources. Thus, the community has evolved an elaborate system of knowledge of the natural world such as species distribution, diurnal changes in the behaviour of the sea, and wind movement. This knowledge is instrumental in regulation of activities in the sea, mangrove forests and around coral reefs. As a result their indigenous knowledge has become an aspect of everyday experience of the marine environment as it helps distinguish the objects of experience, together with their similarities and differences.

Keywords: Culture, ecology, ecosystem, environment, indigenous knowledge, marine resources

Introduction

The Giriama are a bantu-speaking people found along Kenya's north coast. They are part of the larger Mijikenda community that straddles the Kenya – Tanzania border and are highly dependent on marine resources. They have developed elaborate knowledge systems of marine resources over the years. Their indigenous knowledge underpins discourse on the relationship between humans and nature and, therefore, the relevance of indigenous knowledge in the contemporary world (Clifton, 2003). The emphasis here being on the idea that humans' relationship with nature should be dialectical and holistic as opposed to dualistic (Willis, 1990). Giriama indigenous structure and systems of practice (experienced events), belief, and context (CPB), provides an epistemological basis for the understanding of indigenous ecological knowledge.

Paradigmatic Discourses on Human/ Nature Interactions in Anthropology

There is a very rich and elaborate corpus of anthropological literature on various kinds of indigenous environmental knowledge (Shilabukha, 2000; Willis, 1990; Robbins, 2010). For example, traditional agricultural practice is a major field of indigenous knowledge; others include traditional medicine and architecture. It is notable that much of the literature on indigenous knowledge, especially in anthropology, is not about ecological relationships (Berlin, 1975; Hunn, 1975; Chilisa, 2012; Berlin, 2016). Rather, it is about other kinds of ethno-science, including agriculture, ethno-biology, ethno-pharmacology, ethno-veterinary medicine, and ethno-pedology (soils). Some of these areas, for example, traditional practices of water conservation and soil erosion control, are directly related to ecological knowledge, but others such as ethno-astronomy are less so (Posey, 1985). The anthropological shift of emphasis from the documentation and taxonomy of species used by indigenous groups, to a consideration of functional and structural relationships and mechanisms, gave rise to the field of traditional ecological knowledge (Berkes, 1999).

Indigenous knowledge as a sub-field in anthropology borrows heavily from the cultural ecology tradition of the anthropologist Julian Steward (Steward, 1958), who emphasised the study of adaptive processes, and argued that a social organisation itself may be considered an ecological adaptation of a group to its local environment. A number of scholars such as Balee (1989) as well as Berkes (1999) have agreed with Steward's argument. For such anthropologists as Balee, Berkes and others, the emphasis on adaptive processes in human-nature relations as observed in traditional ecological literature, overlaps with cultural ecology, ecological anthropology or anthropological ecology, and anthropology of conservation, but is not a sub-set of these fields because it often goes beyond the discipline of anthropology. However, a number of other anthropologists have criticised Steward's analysis of social reality because they consider it to be deficient in terms of considering other important environmental variables such as disease and population pressure (Acheson, 2003; Williams and Baines, 1993). Steward has also been criticised for being subjective in identifying aspects of what he referred to as 'the affective environment' and the culture core (Netting, 1968; Ellen, 1982; Acheson, 2003).

Figure 1. Map of the research site.

The intellectual foundations of indigenous ecological knowledge are to be found in ethno-science (mainly ethno-botany) and human ecology (Berlin, 1975; Hunn, 1975). Effectively, the field has its roots in the study and documentation of lists of species identified, categorised and named by different indigenous groups, and elaborated a science of folk taxonomies of plants and animals and other environmental features such as soils (Berlin, 1975; Hunn, 1975). These studies are acknowledged in some recent studies, demonstrating how important they were in their influence (Shilabukha, 2000; Majid-Cooke, 2003; Gachihi, 2012). In discussing the evolution of this sub-field, it becomes instrumental to mention that early ethno-botany goes back at least to Barrows' 1900 work on the Coahuila Indians of southern California who made a living in a seemingly barren desert environment by harvesting no less than 60 kinds of edible plants and 28 kinds of medicinal plants (Berlin, 1975; Warren *et al.*, 1995). However, the science of folk taxonomies is often associated with the name of Harold Conklin who in the 1950s documented the extensive plant knowledge and classification systems of traditional groups such as the Hanunoo of the Philippines (Warren *et al.*, 1995).

The rapid development of traditional ecological knowledge as a field in its own right started with the documentation of a tremendously rich body of environmental knowledge, not just of species, but also their ecological relations among a diversity of groups outside the mainstream Western world (Berkes, 1993; 1999). These included studies of shifting cultivation and biodiversity conservation in tropical ecosystems and traditional knowledge and management systems in coastal fisheries and lagoons, semi-arid areas, and the Arctic (Balee, 1989; Berkes, 1999; Callicot, 1994). These studies showed that a variety of traditional peoples, in diverse geographical areas from the Arctic to the Amazon, had their own understandings of ecological relationships and distinct traditions of resource management (Callicot, 1994).

By the mid-1980s, the rapidly growing anthropological literature on traditional ecological knowledge led to a recognition in the international arena of its potential applications to contemporary resource and environmental problems. This recognition is reflected in the report of the World Commission on Environment and Development (UNICED, 1987). Among other things, this report pointed out that indigenous peoples hold a wealth of knowledge based on thousands of years of experience, and that their practices can offer modern societies lessons in the management of resources in complex forest, wetlands, marine, mountain and arid land ecosystems (Majid-Cooke, 2003).

In this study, indigenous ecological knowledge is analysed from the perspective of neo-structuralism. As Mendoza (2000) elaborates, since the essence of neo-structuralist theory is concerned with relating the minute and the large-scale, the short-term and the long-term, presence and absence, it can be applied to local/indigenous knowledge in a global world. The presence of indigenous knowledge has influence on the management and conservation of mangroves, corals and fisheries in many indigenous communities, including the Giriama. In the ensuing analysis, the relationship between indigenous knowledge and the conservation of marine resources is done through studying indigenous knowledge using time-space analysis (Mendoza, 2000). Mendoza's analysis can then be applied to local/indigenous knowledge in a global world. Inference made from this analysis is that the presence of indigenous knowledge has influence on the management and conservation of natural resources in many communities, making the analysis not only relevant to the Giriama context but also applicable to its use and management of mangroves, corals and fisheries. This is because, for the Giriama, many elements of the biophysical environment are imbued with human characteristics. So the community, through indigenous knowledge of the marine ecosystem, relates to these features of the ecosystem on a relational and personal level, making it less likely for the concept of nature to be viewed as separate from humans.

Placing the findings of this study in the context of other anthropological and cognate studies on indigenous ecological knowledge sheds light on how indigenous peoples, such as the Giriama, often depend on coastal resources for various livelihood and subsistence reasons (Zavarin, 1991; Ruddle, 1994; Hale *et al.*, 1998). There are implications for prudent use of resources that allows for adaptive management. This management is a function of lived and experiential learning which have immensely contributed to the emergence of elaborate management and governance systems. These systems have, in essence, evolved a sustainable and symbiotic relationship between the people and resources (Zavarin, 1991).

As a result, these communities have internalised considerable amounts of knowledge not only about the resources, but also their management and use. Of course, if adopted by the larger scientific and policy making fraternity, such knowledge can potentially inform contemporary and future approaches to management. This can happen in two ways. First, indigenous knowledge is a rich source of baseline data to fill information gaps that cannot otherwise be addressed through pragmatic scientific approaches. Second, and more importantly, this knowledge could provide substitute management approaches from which scientists and resource managers might learn. In general, however, little attention has been given to the relevance of such knowledge for resource management (Ihezue, 2007). Acknowledging the existence of such knowledge would be the first step in the direction of plural application in a dynamic future of managing the environment in general, and resources found therein in particular (Shilabukha, 2007; Ihezue, 2007).

The foregoing suggests that the discourse on indigenous ecological knowledge is important for anthropological reflections on a broad range of interrogations related to nature-human relations. This is mainly so because anthropologists treat culture as the most important concept in understanding how different groups of people in various parts of the world perceive and interact with nature (Shilabukha, 2007). Yet indigenous knowledge is part of this culture. Indigenous people's perceptions and knowledge are in part shaped by their values, worldviews, and environmental ethics - religion in the broader sense (Robbins, 2010). This may explain why, in the exploration of environmental ethics and religion towards an ecologically sustainable society, indigenous peoples and traditional ecological knowledge have attracted considerable attention from both scholars and popular movements (Shilabukha, 2000).

In most of the literature reviewed regarding indigenous knowledge, it can be observed that many scholars have focussed on discussions of traditional ecological knowledge and indigenous knowledge of Australian and North American Indian peoples (Balee, 1989; Callicot, 1994) This in not necessarily bad. However, there are many other traditions of ecological knowledge found among various indigenous societies in Europe, South America and parts of Africa and Asia, which also deserve mention (Williams and Baines, 1993). Research and dissemination of information from these diverse cultures will not only enrich anthropological knowledge on the nature/culture nexus, but also stimulate other disciplinary discourses on indigenous knowledge. Such studies will also expand, where necessary and possible, national policy frameworks on conservation. This study is one such attempt.

Materials and Methods

The study was carried in area between Kisauni in Mombasa County and Matsangoni in Kilifi County on Kenya's north coast between June 2012 and December 2013. In Mombasa, the study site included villages in Kisauni and Bamburi, while in Kilifi County, it was conducted in villages in Shanzu, Mtwapa, Takaungu, Mwakirunge, Kanamai and Matsangoni (Fig. 1). (Source: Department of Geography and Environmental Studies, University of Nairobi).

The research site was chosen for the study on the basis of its geographic location and adjacency to the marine resources under consideration. Mangroves, corals and fisheries feature predominantly in the subsistence livelihoods of the people within the research site. Sampling for in-depth interviews was multi-stage. The site was divided into villages along a continuum, then respondents were randomly selected for the interviews. The inclusion/exclusion criteria used were membership of the Giriama community and proximity to the resources. The research design was descriptive-qualitative, and both exploratory and cross-sectional. Data were collected using observation, transect walks, informal interviews, in-depth interviews, focus group discussions (FGDs), and key informant interviews. For the in-depth interviews, 25 men and 15 women were interviewed. For the FGDs sampling was purposive, while key informants were sampled by intensity sampling. In this case, specific groups within the community were targeted, including healers, fishing expedition leaders, mangrove cutters and community leaders. Since most of the data were qualitative, analysis was done through content analysis and presented through anecdotal quotes. Quantitative data were analysed by computation of means, percentages and ranges, and presented in frequencies and percentages.

Ethics statement

The findings presented in this paper were part of a PhD study entitled "*Indigenous knowledge and management systems among the Giriama of north coastal Kenya*". The thesis was examined and passed at the Institute of Anthropology, Gender and African Studies, University of Nairobi in November 2015. A permit for the study was issued by the National Commission for Science, Technology and Innovation. Ethical considerations were observed throughout the study. Verbal and written consent for participation in the study was sought from all the adults recruited after they were given information about the study. To ensure anonymity and confidentiality of the participants, personal identifiers were removed in the final thesis, apart from cases where respondents were insistent on being cited by name. This paper is part of the efforts to disseminate the findings of the study to professional colleagues who may be interested in the thematic area of study.

Results and Discussion

Background characteristics

The background characteristics of the respondents captured were gender, age, marital status and occupation.. Age is an important indicator of the level of knowledge on the marine ecosystem and resources while occupation may indicate the scope of interaction with the resources as well as a factor that determines the position of leadership of activities in the sea and mangrove forests. The gendered possession of knowledge was important, hence the need to record the gender of respondents. In this case, 25 (62.5%) of the respondents were men while 15 (37.5%) were women. In terms of age, respondents ranged from 21 to 70 years. The majority (80%) of the respondents were married, while slightly below a fifth (15%) were widowed. Only 5% were divorced.

The period the respondents had lived in the village ranged from 10 to 70 years, while time of interaction with the resources ranged from 5 to 47 years. One of the elders in Mtwapa described his experience with the marine resources thus:

> *'I am now 72 years and I have grown up fishing since I was 15 years of age. I have practically lived in the sea all my life. The sea is like my home, I know all the corners and the nooks, the fish know me and they come to me.'*

Nature and Structure of Giriama Indigenous Knowledge of the Natural World

Among the Giriama, knowledge is generally tied to the ancestry of experience and is stored in the collective memories of the community elders and experts of various kinds. This knowledge is transmitted largely through non-written processes such as telling stories, creating relationships and establishing personal meaning. Therefore, each generation of fishers and mangrove cutters is expected to pass this knowledge to succeeding generations. Those who teach are mainly the elderly, ready to transit to the world of the living dead. This illuminates the deference and reverence for ancestors; the dependence on knowledge and skills passed from generation to generation. That is why indigenous knowledge on ecosystems among the Giriama is a function of perception, lived experience and interaction with nature. In this way, the community has developed an elaborate system of naming and categorizing the natural world. This system is essentially an aspect of everyday nomenclature of distinguishing aspects of nature through presence and absence, similarities and differences, as well as symmetry and asymmetry. As a result this indigenous nomenclature helps to mentally structure the natural world in relation to word meanings and experiences.

For the Giriama, just like many other indigenous communities, the environment is where all the resources are found and nurtured, including human beings. As the findings of this study indicate, in Giriama cosmology, the environment cannot be divided into different parts. Therefore, the environment, or the world, is a whole whose every component is connected to others. The marine ecosystem, together with all the resources found therein, is important to the functioning of the whole world.

Hence, as a Giriama, when you think about the earth, with all the oceans, with their (tides) rising and ebbing, with the forests and their inhabitants, the moon shining upon them at night and the sun by day, that is the environment. When you think of the water in oceans, rivers, wells, and about the sun in the sky, all the grass that grows from the water, of the rain that falls from the clouds, and the mangroves in the tepid waters of the sea shore; the coral reef and its inhabitants; the deep sea, and the creeks and the lagoons, all the animals and plants in the sea, those we can see and those we cannot see, the estuaries of the rivers that pour from inland into the blue waters; the forests and the animals and plants, and the air we breathe; then the people, who inhabit the land, and use the resources in the sea, and on land. That is the environment. All these make up the environment. Are there boundaries? The Giriama can only fathom contiguous, but not dichotomous borders. They talk about parts of the environment, one by one. Natural resources are referred to as *mali ya mulungu mwenge,* which loosely translates to God's natural (or real) wealth. The Giriama have a strong sense of belief in the supernatural, the reference to God is connected to ancestors, who are intermediaries between the living and *Mulungu* *mwenge* (the Supreme Being). The deference accorded to ancestors allows one to acquire knowledge about the resources as well as how to utilise them.

In this community, the natural world is considered sacred and the property of the Supreme Being (*Mulungu).* According to the participants in one FGD at Mtwapa, *Mulungu* directs how the resources should be used because they are sacred and belong to everyone in the community. Some mangrove species, coral reefs and fisheries are not touchable. In some instances, seasonal bans are pronounced on some sections of mangrove forests or the sea, or some species. These bans are enforced until certain rituals or ceremonies are performed. Thus, community members inherit knowledge about the environment from their parents and experts who obtained it from ancestors; the custodians of this information. Because the environment is imperative to the Giriama people, this may explain why the community retains knowledge of different environmental features and their place in the ecosystem.

Since all the resources are considered the property of the Supreme Being, the spiritual connection between the human and natural world is apparent. However, some resources are particularly deified and considered the property of ancestors. This is typical of particular medicinal plants in the mangrove ecosystem, or entire mangrove forests, creeks and coral reefs. Some fish species are also considered taboo due to biological as well as symbolic reasons. For instance, mangrove species such as *mchu* are considered to be the house of sea spirits and so must be taken care of meticulously by herbal healers. Andersen *et al.* (2004) found similar ideas in their study on traditional ecological knowledge among the Eskimo people of Alaska in regard to subsistence harvest of non-Salmon fish in the Koyukuk River Drainage.

Many other anthropologists have similarly found connections between knowledge of the natural environment and the complex of context, belief and practice in areas inhabited by indigenous communities. In Tonga, for instance, Malm (2009) found that what one sees depends on what one knows. And what one knows is a function of how one was socialised to know. Among the Giriama, people have gained deep insights based on interpretations made in connecting life with the ever-present nature. That is why the concept of the environment is understood in many ways as demonstrated in the community's representation of space, and what it comprises.

This is also the reason why the distribution of indigenous knowledge on the marine resources is not homogenous. It is differentiated according to experiences, gender, age and occupation of individuals in regard to interaction with the resources. In reference to diverse occupations, rain makers, healers, fishing expedition leaders, those who perform rituals of an environmental nature, and some with multiple roles, were identified in the present study. The ritual, spiritual, religious and physical value of the resources was captured vividly by the respondents.

Considering indigenous ecological knowledge according to gender among the Giriama, men spend more time outdoors compared to women, hence they interact more with the resources compared to women, an aspect of the gender roles and ritual occupation of the public and private spaces in the community. Thus, the roles of cutting mangroves, building and fishing are part of men's public domain activities. The implication is that men are knowledgeable about mangroves and fisheries, their distribution and characteristics. Men are also responsible for carrying out rituals related to mangrove cutting or fishing. Women are responsible for gleaning, picking those species found near the shore or shallow waters. Women are also healers; they collect leaves and roots of the mangroves. This utilisation is also an indication of who is most likely to have more knowledge on which resource found in the mangroves. This information is summarised in Table 1.

Like other communities, the stock of ecological knowledge is distributed differently in the Giriama population, whereas culture is understood in terms of sharing, depending on spatial, social and cohort experiences. Indigenous knowledge gives the Giriama individual the capacity for orientation with marine resources. The knowledge structures the individual's understanding of the world, and provides purposeful ways of acting, guiding interaction with marine resources, and providing rules of extraction and utilisation through context, practice and belief. This then lends itself to management efforts, leading to conservation outcomes layered in terms of age, gender and occupation.

Indigenous Knowledge and Classification of the Features of the Natural World

For the Giriama, natural environmental features can be divided into land, water and air. In this classification, land is the area of the environment which is dry. There is no river, lake or ocean water on it. It is locally referred by the Kiswahili phrase *nchi kaavu*. Water is to be found in lakes, rivers and the ocean. Air (*hewa, anga*) is unseen. All these components of the environment are useful. The Giriama, like many other indigenous communities, classify the environment through cognitive or oral maps. These maps undoubtedly reflect the worldview of how the land and seascapes are organised and utilised. The use of lexical categories to identify eco-zones that reflect the local inhabitants' intimate connection with marine nature come into place. Similarly, symbolic kinship ties with the natural environment is often based on a strong spiritual connection with Giriama ancestors and the land where their ancestors are buried, as well as on subsistence needs.

Therefore, these maps reflect social behaviour and aspects of marine resource use and conservation. For the Giriama, these oral maps serve as a framework from which to operationalize local lexical items that may serve as part of the cultural code for aspects of biogeographic categories. Because the very nature of many indigenous societies' lexical items is spatial in nature, it allows for the mapping of terms to form a graphic representation of oral (cultural) maps of various marine ecological zones (including reef locations and fisheries movements) and human activities. This is the basis of marine environmental classification. Those who have the knowledge use it routinely, perhaps every day, and because of this, it becomes something that is a part of them and unidentifiable except in a personal context. These personal cognitive maps are created through humour, humility, tolerance, observation, experience, social interaction, and listening to the conversations and interrogations of the natural and spiritual worlds.

Furthermore, the ritual, spiritual, religious and physical value of the resources was captured vividly by the respondents. According to one female healer in Bamburi, the environment is the provider of food and livelihood. It contains the resources the community is interested in. But remember some parts of the environment cannot be utilized for anything. These places are used for performing traditional rituals of the community to cleanse the environment. The Giriama call them '*palani*'. Such spaces are mostly used by the community elders and the diseased who attend the rituals. Young people may not be allowed into these areas.

The physical world is very important to the Giriama people. According to the accounts of the respondents, it provides building stones (*timbo za mawe*). These stones are dug just like minerals from the ground. The stones are, however, not deep into the ground. Hence the local individuals find an easy task in getting them and putting them into their preferred shapes. The environment also provides building poles for their houses. Some poles are obtained from the mangroves (*fito)* and others from the trees available in terrestrial forests. In addition, the environment provides food for the people and space for shelter of the people living there. The clean air people and other animals breathe is provided by the environment. According to the respondents, environmental features can be classified into natural and artificial, or human-made features. Natural features are those features that grow on their own. They are formed by natural forces or powers. They could also be attributed to supernatural forces or powers. Artificial features, on the other hand, are features which are made or planted by human beings in the environment.

Table 1. Use of the mangrove ecosystem.

Type of activity	Gender of users	Use
Cutting of trees for poles	Men	Poles for house and boat construction
Collection of medicinal extracts	Trained men and women	Healing and performance of rituals
Collection of vegetables	Women and girls	Domestic consumption
Collection of firewood	Women and children of both sexes	Sale and domestic use
Harvesting of crustaceans and molluscs	Women	For domestic use and sale

Source: Author, 2013

One of the areas of interest are the terminologies used to refer to environmental features in the local language. To set off the naming of the environment, we may begin with the term environment itself. Among the Giriama, the term environment is related to other categories of naming; the closely related concepts are space, weather, climate and time. The concept of the environment is referred to as *mazingira,* which may also mean surroundings. This term has its etymology in the verb *kuzingira*, meaning to surround. Indeed, this is the same term used in Kiswahili, the dominant language in East Africa and the national language of Kenya.

Climate, on the other hand, is referred to as *musimu,* which may interchangeably refer to season. The term is also found in Kiswahili. The term for the weather is *dzoho*, while space is referred to as *nafasi,* and time is *wakadhi*. It is notable that *dzoho* also refers to temperature, particularly high temperature. Natural resources are referred to as *mali ya mulungu mwenge,* which loosely translates to God's natural (or real) wealth. It is remarkable that the Giriama have a strong sense of belief in the ancestral spirits. In this case, the reference to God is connected to the ancestors, who are considered intermediaries between the living and *Mulungu mwenge* (the Supreme Being).

As the findings of the study indicate, the Giriama people perceive the natural world in ways that suit them and their particular context through a strong tradition of spiritual and cosmological ties to environmental knowledge. This knowledge is rich, diverse and vibrant and it helps the community to adapt to their physical environment, biologically as well as ritually. This ties in with anthropological interest to relate ecological survival to cultural institutions that pursue livelihoods (Kuper, 2014). It is apparent that the Giriama practice 'ecological survival' in their relationship with nature, through indigenous knowledge. Therefore, the community takes the physical world and the resources found in it as much more than a set of material possibilities to which their culture, social organisation and kinship system have adapted, for provision of materials for reflection and premises for action making the concept of 'knowledge' to situate itself in a particular and unequivocal way relative to events, actions, and social relationships (Barth, 2002).

For this community, an important aspect of the marine environment and resources is the sea. Locally, referred to *ziwa* or *bahari,* the sea is an important aspect of the natural world because seawater is the home of the many useful marine resources. In the indigenous cosmology of the Giriama people, seawater is both a living and a non-living feature of the marine environment. It is living because it provides life to all the plant and animal species found in it. It is non-living because it does not have life of its own. In the words of one male elder in Mtwapa, there is an umbilical relationship between sea water and those resources found in the sea. He intimated that the sea water itself is a living thing. It breathes life as it has clean air that it gives to creatures living in it. It also cleans itself after the creatures have deposited their waste products. It is the creatures which make the sea complete. The sea cannot be complete without the creatures and physical features found in the water. Likewise, the sea creatures and physical features would be naked if the sea was to be wiped away, and they would not exist as we know them. The sea is a big living thing.

In Giriama cosmology, an interesting aspect of the marine environment, in particular reference to sea water, is the assertion that the sea is not a massive boundless body of water. In that sense, the sea is demarcated in terms of cognitive or oral maps through lexical categories which reflect the worldview of how the land and seascapes are organised and utilised. Cognitive mapping allows for the formation of a graphic representation of oral (cultural) maps of various marine ecological zones (including reef locations and fisheries movements) and human activities. According to one elder in Kilifi, the sea has plenty of marks that nobody sees; it is only the leader of the expedition who knows these routes. They are his secret power over the rest. When he is *tired* (old) and wants to retire, he will leave the secrets to his son.

The cognitive maps are important for fishers and those working in the mangrove forests. These maps are facilitators of knowledge about the spatial distribution of resources in the sea as well as mangrove forests, such as coral mining areas, fishing spots or mangrove cutting areas. This knowledge is converted into concepts which are frequently named, especially if they are socially and economically important linguistic reference points. Therefore, finding a fishing spot in the immensity and vastness of the sea is not about luck. Each fishing expedition has a leader and that leader must be competent to sail at night guided by the position of the moon and stars, whether physically visible or not, in order to locate the best and most productive fishing grounds. The leader should be vastly and proficiently erudite of the routes in the vast sea, by use of cognitive maps. According to a renowned fisher in Kanamai, the cognitive maps are constructed through observing routes of water running along the direction of coral reefs and the caves found in the sea. Each expedition has its own system of routes that is not used by any other. The more routes the expedition leader discovers and keeps surreptitiously secret, the more fishing spots he claims and the more veneration he gets within the community.

The cognitive maps for the Giriama can be inferred to imply the use of their gen and ken of the marine environment to represent the spatial dimension of important geographic features on the landscape and seascape. For thousands of years mental, physical or oral maps have been used for defining boundaries of sacred and secular spaces on land and sea among many indigenous communities around the world. This has then been used for depicting the location of important resource zones and sacred sites. For instance, in a study of mapping customary land in East Kalimantan, Indonesia, Sirait *et al.* (1994) found that the combined use of oral histories, sketch maps and GIS and the Global Positioning System (GPS), could be instrumental in mapping customary land tenure and comparing villagers' perceptions of land ownership and land use to those of the state. This has also been demonstrated by Alexander and van Djik (1996).

Mangroves, fisheries and corals hold a very special place in Giriama cosmology. Some wearing worn out boots, others barefoot, fishers, mangrove cutters and the coral reef explorers wade into the deep sea from the shallow muddy shore, or make their way into the sea through the forest. Over the years they have learned everything there is to know about the fish types, the trees in the lush forest and the shiny underwater seascapes that form the corals and the reef. They know all the species and their associates. Without the sea water, there would be no fisheries, mangroves, nor the reefs and their inhabitants. And without the mangroves, there would be no forests; without the forests, there would be no trees.

Therefore, the Giriama also identify, name and classify marine resources as part of their indigenous taxonomy which forms an integral aspect of the community's indigenous ecological knowledge. This knowledge stems from the fact that traditionally, the Giriama depend on the resources and exploit the environment for rituals and livelihoods, hence the need for classification. The community uses various criteria to classify the resources. For a start, marine resources are classified into inter-tidal zones, the mangrove forests, the coral reef, and the open deep sea. The classification of the areas has remarkable geo-spatial as well as ritual significance.

Mangroves form a very important part of the natural world in general and marine ecosystem in particular. For the community, the forest exists because the trees have not been cut down *en masse*. As exemplified by a 67-year-old elder at Mtwapa, the forest is part of the creation given to their ancestors for their children and the children of their children in the distant future. The mangroves have medicinal and aesthetic value. The bark of the mangroves and their leaves can be used for medicinal purposes. They are also used to heal the wounds of the circumcised. Dyes processed from the bark can also be extracted and used to colour the women for beauty purposes. In modern times, mangroves have attracted many tourists, both domestic and international, to the region.

Therefore, mangroves are not just the fringing vegetation along the lagoons, estuaries and creeks. They are a major source of livelihoods and have esthetic, spiritual and cosmological significance. Mangroves also provide important nursery, shelter and feeding habitats for a wide array of fishes, crustaceans and molluscs, which are utilised in commercial and subsistence fisheries. Mangroves also provide medicine and firewood apart from providing shade for the *mirindi*, (seaweed), which women collect for subsistence as well as commercial use. Young women only collect *mirindi* and firewood and only those who are trained in medicinal herbs can access trees with medicinal properties as these are the property of the ancestors. Ancestors can only talk to those who are invited to the trade. Among the women, it is those who no longer menstruate, or have stopped giving birth, that are invited.

According to some elders in Matsangoni and Mwakirunge, the significance of the mangroves is further demonstrated by the presence of three birds; *shake* and *membe,* types of egret, and *nyange nyange,* the kingfisher. These birds nest in the mangrove forests and feed on the fish that nest or hide in the forests. There is a symbiotic relationship between the fishers and the birds. Any area of the sea being overflown by many kingfishers and egrets is an indication that many fish, particularly prawns, are in the water. The fishers then move in rapidly to catch the fish. This is the root of the friendship between humans and the two bird species referred to above. They are appropriately called 'friends of the fishers'. The kingfisher particularly feeds on prawns, locally known as *mashaza*, a local delicacy. The small sizes of the prawns make it difficult for fishers to locate them in the sea water.

The community acknowledges that mangroves are home to many aquatic animals. According to the respondents, *kaa*, a generic name for all crabs, are the most conspicuous invertebrates inhabiting mangroves. There are also fish, which feed on plants and other animals in the mangroves. Apart from the aquatic animals, there are bird species such as the great white heron (*membe)*, which feed on the aquatic animals. This was summarised by one 55-year-old male respondent from Shanzu as follows:

> *'The upper zones are inhabited by those crabs that do well in marshy areas. Then closer to the shore we have others. On top of the roots we have prawns and shrimp. Some of the crabs feed on small organisms and this helps in fertlising the ecosystem. Other crabs feed on some snails. We harvest smaller crabs for food. There are also oysters, which secure themselves to lower stems of the mangroves and suck plankton and other food from surrounding waters.'*

Another function of the mangroves is to provide protection for the dry land from the invasion of the sea water during high tide. According to the women's FGD in Matsangoni the waves from sea water are very strong and wash everything standing in their way during the high tide. The mangroves act as a blockade for the water. In this way, erosion is prevented by their presence. Our fathers knew about the important nature of these forests. They, therefore, did not uproot or deplete them. For the Giriama people, the mangroves have many uses and these are not limited to the trees. There are other resources found in the mangroves and the waters surrounding them. As pointed out earlier, these resources are extracted according to age and gender.

The Giriama have a system of classifying and naming the mangrove ecosystem. There are species and sub-species in the ecosystem. For the Giriama, the mangroves not only refer to the trees found in the intertidal zones, but also the animals. Discussions with the elderly respondents revealed that the mangroves actually divide themselves in zones and stages from inland into the sea. According to one 57 year old male respondent at Matsangoni:

> *One can observe the stages of division of the mangroves from a distance as they grow. It is as if they divide themselves according to the conditions. There are three zones in any mangrove forest. In the first zone, which is nearer the shore, the trees are hard, narrow, have narrow whitish leaves and are strong. Here the trees regenerate through dropping their seeds in sandy soils. In the second zone, the middle one, the trees are bigger and softer with whitish leaves. Here, the trees regenerate through vegetative propagation. This means twigs fall into the muddy soils, anchor themselves and germinate immediately. In the last zone, deeper into the sea water, the trees are softest with green, broad leaves. Here, the trees regenerate through seed propagation.*

Generally the mangroves are referred to as *mikoko,* the plural of *mkoko*. The term *mkoko* itself has the connotation of strength, fortitude and sturdiness in the community's metaphors. It is, however, important to note that *mkoko* in the real sense refers to the commonest and most widespread of the species, *Rhyzophora mucronata.* This is the hardest of the species. As described by the respondents, the *Rhyzophora mucronata* trees are of average size and have stilt arch and prop roots that function to strengthen the tree stand.

Another species described is locally known as *mlilana* (*Sonneratia alba*). The bark looks almost white although shaded brown. At times it also looks like ash. It has normal roots like other trees and the leaves are rounded and leathery. The flowers are white and pom-pom-like and open only for one night. Their fruits are large, green, leathery berries with a star-shaped base and have many seeds, which are white and flat. Its wood is mainly used to make canoes, boat ribs, paddles, masts, Smith pneumatophores used for floating fishing gears, as well as window and door frames. It may also be used for firewood and charcoal.

The *mkandaa (Ceriops tagal*) is a tree that has many shapes and sizes, according to the respondents. It is also called *mkandaa mwekundu* (the red *mkandaa) or mkoko mwekundu* (the red *mkoko).* According to the men's FGD in Kanamai, it is the tallest among the mangroves. Then there is *muia/mkoko wimbi (Bruguiera gymnorhiza)* whose seeds germinate while still attached to the tree. Its alternative name, wimbi, means wave. Its growth is characterised by a wave-like development. After the seedlings are released they fall vertically into the mud and become established rapidly. The tree likes very salty areas where it can grow up to 20 metres. Absence of salty conditions stunts its

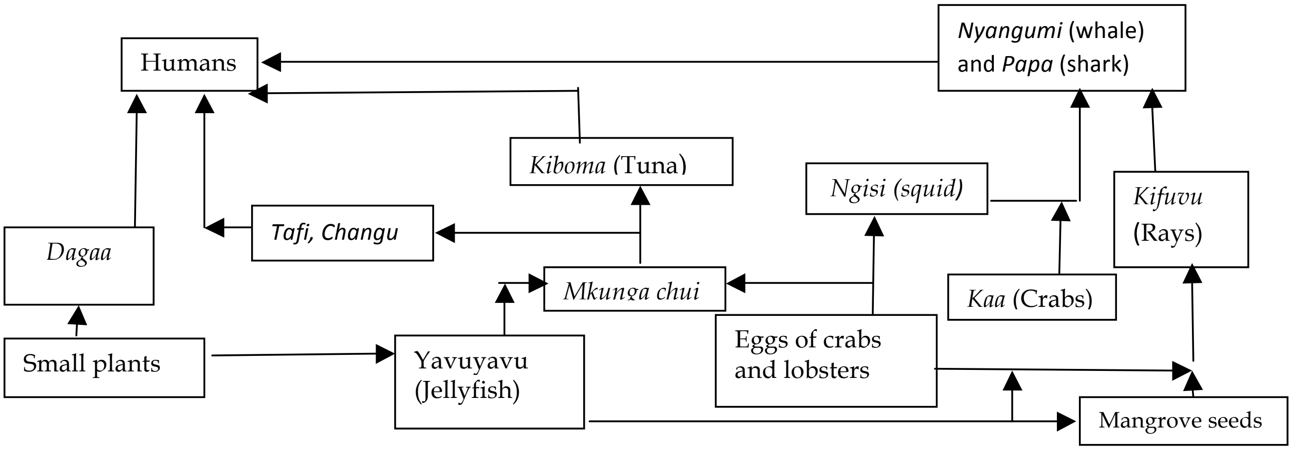

Figure 2. An indigenous food web and trophic levels for marine organisms.

growth. Its wood is used mainly for building material, roof supports and firewood.

Another interesting species is *mkomafi dume* (*Xylocarpus moluccensis)*, which literally translated, means the male type of the tree. However, it is rare in the area where the study was conducted. The leaves of the tree are less leathery and lighter green than those of other species, and the end of the leaf is pointed. The tree has underground roots just like other terrestrial trees. The respondents also named and described the looking-glass *msikundazi,* also known as *mkungu (Heritiera littoralis).* Another species is *kikandaa (Lumnitzera racemosa)* which, according to one male respondent in Shanzu aged 47 years, the local people refer to as the black mangrove or the small *mkandaa.* Finally, there is *mchu* (*Avicennia marina*), which is sometimes referred to as *mtu* (person). It is also called *mtswi* (or white mangrove). The white mangrove is considered sacred among the Giriama people.

Another important resource are corals and coral reefs. They are known locally as *matumbawe* and *miamba ya baharini* (rocks of the ocean), respectively. They are classified at two levels. One parameter is according to the amount of life found in them. Thus, dry (or dead) rocks, and the living corals which are still breathing, are identified. The first category are found along the shore or inland where there is no water to nurture them. They are effectively dead. Corals are also classified according to the size of the rocks, which is also a function of their location. In this case, there are those found in the open sea and those found in the creeks. Those found in the open sea are bigger in size compared to those found in the creeks. Coral reefs provide habitats for marine fish species for feeding and spawning. Corals and coral reefs are the houses and resting places for some fish species. Additionally, they provide fresh air for the fish which they take in through their breathing organs, gills (locally called *mathefu*).

The Giriama classify all the animal species found in the sea as fish (*samaki)*. The number of aquatic organisms distinguished and named by the Giriama fishers is substantial, reflecting both the extent of indigenous knowledge they possess and the species diversity characteristic of the coral reef areas, mangrove forests and the deep sea. In classifying the fish, there are those species found among corals, those found in mangroves, and those found in the open deep sea. The location of the species is a function of adaptation to the conditions as well as their survival needs.

The respondents could construct food webs and energy levels based on interaction with resources over a long period. At the lowest point are species that feed on planktons and mangrove droppings; they include *mkizi* (cuttlefish) and *tafi* (mudfish). Then there are the *changu* (Variegated emperor) that feeds on other species such as small crabs and worms. Then there are the *tewa* (Rock fish) that approaches the higher echelons of the food chain because it feeds on other fish species. At the top of the chain are *nyagumi* (the whale), *papa* (the shark), and *Pomboo domo-refu* (the dolphin), which respondents indicated do not lay eggs, but give birth. The dolphin is the most intelligent and it feeds on sea grass and weeds. Another species is the barracuda, locally called *tangesi,* and *ngisi* (squid) which feeds on other sea species. The food web and trophic levels in Fig. 1 was constructed from information gathered from elders in a participatory process. It is based on the description of the food different fishes feed on. Therefore, much as the food web may resemble a typical scientific one, although derived from indigenous description, and implies that these fishers have deep knowledge on the food webs and trophic levels in the marine ecosystem.

Giriama knowledge of the larger ecosystem and the relationship between different aspects of it which provides habitat for valued marine species includes broad physical and biological features such as the deep sea itself, the inter-tidal zone, the shallow areas of the sea, and the outer border where it drops off into the ocean depths. Therefore, for the Giriama, the environment is not a "vast blank slate" in the ordinary course of life, a space simply awaiting the imposition of cultural order. Instead in the course of their daily interactional activities, people acquire intimate knowledge of the environment, and discover meaningful patterns.

Evidence for this may be found in their ecological knowledge in general and taxonomic naming of various elements that exist in the marine environment. Their dependence on the marine resources highlights the relationship between their perception of the physical characteristics of the environment and the social production of knowledge. Thus, the lack of a particular word in the local language that denotes environment does not imply that the community cannot perceive and categorise the environment. In fact, different aspects of the natural world are aptly and elaborately differentiated and named by the community, such as the different mangrove and fish species, according to location, characteristics and use. The vast ocean is also categorised along utilitarian as well as ritual and symbolic schema.

In their own studies, anthropologists Fraser *et al.* (2006), Diegues (2001), and Cunha (1997), have also brought to the fore the cultural perception of the relationship between land and sea space, highlighting the perception indigenous people have of the relationship between physical characteristics of the environment and the social production of knowledge. Among the Giriama, knowledge of the environment is culturally produced, accumulated through professional practice and continually recreated according to the features of the maritime environment which presents itself as cyclic, mobile, and unpredictable. The appropriation of the sea and its resources is expressed in the principle and practice of 'knowing-how', and marine territory is constructed and ritualised by means of tradition, apprenticeship, experience and intuition.

This is similar to what Oso (2007) found among the Yoruba of Nigeria. In this community, there are villages which specialise in producing herbal medicine. Some of the herbs used in healing grow naturally, while others are planted. Similarities between the Yoruba and the Giriama in this case is the transmission of the indigenous knowledge about natural resources as well as the linking of the resources to the supernatural. Among the Yoruba, plants are part of the broad aspect of life; they maintain their personality, individuality and psychic space. Each plant has its own aura, surrounding magnetic field, and relates to the *universal energy* in terms of floral consciousness. This knowledge is transmitted to herbal healers through spiritual visitations, visions or trances.

Indigenous Meteorology and Seasonal Work on Fisheries, Mangroves and Corals

The local community has internalised the weather changes that influence the tidal schedules over the years. Thus, fishers and mangrove cutters work according to a natural tidal timetable. In case of changes, they have to wait for three days to a week before the new tidal schedule normalises and the sea settles down to welcome them back. This is important knowledge for this work in the sea, fishing or cutting mangroves. The fishermen monitor changes in climatic conditions by observing. For instance, dark, grey clouds indicate the onset of rainfall, while increase or decrease in water temperature and change in the direction of wind indicate a change of seasons. Another source of meteorological knowledge is the profound knowledge of the behaviour of the sea in terms of wave turbulence and water colour.

The colour of the seawater is key in predicting tidal and weather changes. If the water is dark (described as dirty) and turbulent, such that one cannot see beyond a few centimetres, rain is on the way and no activities should be undertaken in the sea or mangroves. Otherwise, if the sea is clear and calm, it is safe to go fishing and mangrove cutting. These indications are also important for catch prospects. The colour green, according to older fishers, is a positive signal because it signifies "fertility" of the sea. This colour is due to the abundance of algae on which some fish species feed. According to one of the fishers:

> *The sea always appears "blue". This does not indicate barrenness. This is because some fish species such as papa (sharks and rays) are caught in blue looking waters. The weather changes enable people, especially fishermen*

> *to know the behaviour of fish. These behaviours change with changing weather conditions. We are also keen on the colour appearance of the corals. They change from dark to shiny with changing weather conditions.*

The behaviour of mangroves, fish and corals are not only indicators of change in weather and climatic conditions, but also an indicator of the effect of weather on the resources. According to mangrove cutters, heavy rainfall that carries soil and other rubbish to the mangrove ecosystem leads to flooding that covers the breathing roots of the mangroves, which can then die. Therefore, rainfall can cause negative effects on mangrove forests. Strength of the wind also affects the mangroves as heavy winds can break the branches. Temperature also affects the mangroves as it enhances evaporation that exposes the breathing roots making them die. Weather elements also affect the regeneration of mangroves. The FGDs reported that during the cool season, when there is limited sunshine, the ground on which the mangroves grow is very soft and wet. Some mangroves shed their fruits; these fruits are very sharp at the end facing down. On falling, the fruits penetrate the ground, after which the seed inside the fruit germinates leading to regeneration. Corals are also affected by climatic conditions in various ways. Heavy rainfall leads to floods from the rivers. These cover the corals and kill them. Very high temperatures lead to evaporation of the waters hence exposing the corals, which die.

The inference here is that weather, especially temperature, also affect species distribution and migration. High temperatures usually bring many fish to the shores. Wind direction helps fish locate their food and enemies and so contribute to species distribution, behaviour and migration. Clouds also offer clues for interaction with marine resources and the concentration of the clouds in the sky is key, as this influences catch prospects. Heavy cloud cover, known as *kolowa,* leads to the presence of many fish; a positive prospect for fishers. Fish usually breed during the cool weather or season when there is moderate sunshine for the survival of the young fish. There are some fish species that thrive in windy and cloudy conditions, for example, the shoaling *simsim.* These are a delicacy, and they are dangerous to follow. One elder at Mtwapa revealed that it requires expert fishers who know the sea maps to follow and catch them. The maps are dictated by the direction and strength of the winds, hence the paths to be followed by humans.

A fisher in Kanamai intimated that climatic factors affect the way the community interacts with the marine resources. The major factors are rainfall, wind and temperature. During the rainy season, fisheries migrate from the deep sea to the shores. This is for cool temperatures, which are preferred by fish. This means fish species distribution is due to the temperature of the water. We also know that rainfall supports the existence of fisheries depending on the fish species. Some fish species such as *pono* appear most in rainy seasons while others appear when there is no rain, such as *simsim*. Wind direction enhances species security. Clouds also offer clues for interaction with marine resources. In monitoring the clouds, the community looks at the concentration of the clouds in the sky. As mentioned, heavy cloud cover, known as *kolowa*, leads to the presence of many fish, which then means positive prospects for fishers.

Corals are also affected by climatic conditions in various ways. According to the respondents this is because they are alive, and they breathe, grow and, finally, die. In Takaungu, a female healer informed us that when corals change in appearance and become shiny it is an indication that heavy rainfall is on the way. The shedding of leaves by the mangroves and the appearance of certain fish species is also an indicator of heavy rain on the way. This also has prospects for catching fish and working in the mangrove forests. Fishers keenly observe these signs from nature, which they have observed for a long period. This also has implications for catching fish and working in the mangrove forests.

Meteorological and climatic insights depict knowledge on seasonal behaviour of living and non-living aspects of the environment. The Giriama have internalised the names and behavioural patterns of mangroves and fish species, making it possible to know when and where to catch certain fish species. This knowledge regulates activities in the mangrove forests as well as the sea. Those going into the sea or mangroves must take note of the schedules and seasonal changes such as temperature, wind, waves and cloud cover. It is noteworthy that fishing is an occupation undertaken as a family, clan or lineage, meaning that knowledge about fish behaviour is kept within these confines of the community, although this information is available to those who wish to join fishing as a profession. In his study in Msambweni, Kwale County of south coastal Kenya, Shilabukha (2000) found similar ideas among the Digo community regarding mangroves. This is probably because the Digo are also a Miji-kenda community.

In their studies, Wagner and da Silva (2014) and Drew (2005) have demonstrated that indigenous meteorological expertise is used in forecasting weather and seasonal changes in many indigenous communities around the world. These studies have identified and documented evidence which reveals that communities observe changes in their climate over long periods of time which then enable them to correctly predict atmospheric changes. Through this knowledge, communities have substantial understanding of what goes on around them and how they should make adjustments to ensure their livelihoods continue.

Indigenous meteorological knowledge has also been noted by anthropologists regarding plant and animal behaviour which responds to changes in the weather. Among the Tallensi of Ghana mammals, birds, worms and even reptiles have been observed to provide clues on changing weather and seasons in a given year (Gyampoh and Asante, 2011). The movement of a certain bird which looks like a duck or cattle egret, locally called *haahor,* indicates seasonal changes. When this bird moves from the south to north, making its sound "*Kwaaa kwaaakwaa",* it is an indication that there will be plenty of rainfall. When the bird flies southwards, it is an indication of less rain, an approaching dry season, or in some cases, drought. Likewise, when a species of an old frog, locally referred to as *yakase,* are heard in May to June, it is a sign of the rainy season approaching. Their sound is said to call the rains, so when they are heard together at a certain time of the year, it means it is time for the rains. Using this signal, farmers can begin preparing their fields for the planting season. The frogs are usually heard in June or July (Gyampoh and Asante, 2011).

In the same community, it was reported that a tree known as *kakapenpen* or *nkudua,* is also closely monitored for clues of imminent change in weather or season. The fruit of this tree does not always ripen, therefore, when it bears fruit and the fruit ripens, the rainy season is near (Gyampoh and Asante, 2011). These anthropologists have also found that the Tallensi use the behaviour of invertebrates to predict weather changes. When millipedes and centipedes are observed climbing to higher grounds when the rainy season begins in July, it is an indication that the community will experience flooding. They then begin to build traditional dykes and canals to guide the water from the rain so as to alleviate the impact of the flooding in the community.

From these studies, it can be inferred that Giriama meteorological knowledge is part of the fusing of the physical with the cultural. Indigenous knowledge about seasonal and weather changes reflect the fact that the Giriama are thoroughly acquainted with the biology, physics, and geography of their terrestrial as well marine environments. This knowledge is also a reflection of perception involving process and self-organisation, making indigenous knowledge a guiding metaphor. Therefore, indigenous meteorology should be analysed and presents as the master science of ecological survival for the community. In the same way, Ruddle (2000) notes, 'resource use patterns among indigenous communities are products, not of the physical environment and its resources *per se*, but of their perceptions of the culturally formed images of the environment and its resources'. Thus, to properly understand human ecological relationships, climatic and weather patterns, it is crucial to get a firm understanding of a society's indigenous knowledge base, and the cosmological system underlying it.

This may explain why indigenous ecological knowledge of climatic and weather patterns is the reason why fishing is not undertaken all year round among the Giriama. The fishing season begins in October and ends in April. The climatic conditions, especially the direction of the wind, are a factor to consider. Fishers have internalised these conditions. The south to north winds herald the beginning of the dry season, *kusi.* Fish swim along with these winds. This is the time to go fishing because the sea is generally calm and the temperatures low. When the winds change direction, the sea begins to change colour and becomes rough. It is dangerous to go into the sea in such conditions. This is the beginning of the wet season and, therefore, no fishing takes place. Fishing is regulated in this way. The species availability and catch differs in different seasons. Some species appear during the wet season while others appear during the dry season, and others are present year round.

In this regard, Giriama indigenous meteorology identifies and recognizes two seasons in the normal calendar year, which are affected by the direction of two seasonal winds, *kusi* (blowing south to north) and *kasi* (blowing north to south). The two winds have different hydrological and temperature implications. These climatic and seasonal factors affect the way the community interacts with the marine resources. The major factors are rainfall, wind and temperature. Therefore, the ecological experts in the community monitor the climatic conditions that affect the resources for the onset or end of the fishing season.

The fishing season must begin with an elaborate ceremony consisting of many rituals. A group of fishers prepare a meal of rice and what they refer to as *samaki mabaki* or “wasted fish”. The “wasted fish” are those caught for the first time at the onset of the fishing season. They are referred to in that way because they are remnants from the previous season. After the preparation of the meal, the fishers take their boats to a central place in the deep sea and anchor them. This specific place is called *kitwani* (at the head), where fishers of an expedition go to at the beginning of every season. There are many *kitwani* places in the sea. The choice of the site is based on tradition, although no reason was given for its choice. A number of rituals are performed including prayers, and libations are poured into the sea to appease the gods, ancestors and other spirits. After the praying they burn *ubani* (or incense). It is here that the installation of new fishing expedition skippers occurs.

To confirm that their prayers have been received well, one of the party must experience a seizure and is then given *chetezo,* a small water vessel, and a wooden sculpture called *chano,* and dives into the sea to commune with the ancestors and spirits of the sea for half an hour. The vessel contains ashes of burnt incense which is believed to appease ancestors and mollify malevolent spirits in the sea. The sculpture is itself a piece of abstract art. It is a generic representation of ancestors, the reason why it is gender-neutral.

At the end of the half hour, the one in the water resurfaces from the deep sea unscathed. Upon his re-emergence, the ceremony begins in earnest with the eating of the food that was carried to the open sea shrine. After the ceremony, the fishers disperse and this marks the beginning of another season of plentiful fishing. The fishers are very categorical that the ritual is about minimising negative events such as drowning while at sea. They acknowledge that they cannot eliminate them all, since there are some individuals in the community who will still commit crime that will attract the wrath of ancestors and the repercussions of these crimes will affect even innocent people in the community.

The identification and choice of a particular spot in the open sea is puzzling to a casual observer. However, according to Maldonado (1997), the ability to identify particular zones of the sea and to find one’s bearings in the midst of the immensity of the sea, out of sight of land, is part of what he refers to as ‘the cognitive skill set of fishermen’. This ability seems to be the direct and accumulative result of continuous interaction between many fisher communities and the marine environment. In a related study, Wavey (1993) found that elders in Manitoba, Canada, teach skills and maintain continuity and links to community resource areas by transferring highly detailed ‘oral maps’ and inventories of resource values and land use to their younger members.

If the choice of the place called *kitwani* is considered, the ritualistic and sacred nature of the location points to a coterie of observances which, from a superficial viewpoint, could just be another superstitious ceremony undertaken every year. From an anthropological and analytical perspective, this place and the ceremonies that take place there, are part and parcel of the wider cultural picture of the marine resources. The ceremonies also point to the beginning of the fishing season, because prior to the ceremonies, no fishing is allowed in the sea. The elders are aware that many fish species spawn during the period of inter-seasonal rest for the fishers. Thus, these prohibitions and taboos are used to mask the natural cycle of replenishment.

The immersion of the man in a trance makes him the messenger to the origin of the community, which connects the distant past through the present to the near, yet unforeseeable future, deep into posterity for the continuity of the community. He goes to commune with the ancestors to bring back fresh knowledge about the sea and the land for the new season. He is the connection to the origin, differentiation, migration and creative deeds of the ancestors, starting from the very beginning of the world and continuing with the establishment of the traditional order and leading to the roots of the present generations that may bring forth posterity. This immersion also anticipates the contemporary culture as the creation of the distant past indigenous knowledge of nature unfolding in utilitarian categories of classification, management and use. The immersion pieces together the prelude to the awareness that led to the identification and subsequent classification of the components of the empirical environment which forms the basis for contemporary ecological behaviour. The immersion also reveals the geography of the sea that is at once mythical and real, thus serving as the basis for behavioural options within this territory.

This ritual can be explained as a model of reality that combines myth with the empirical nature through culture because it brings forth information about the coming season. The gen and ken is defined and deified through the borrowed authority of the ancestors and other benevolent spirits of the sea. This ritual seeks to deflate and deflect the influence of negative forces of nature in the sea. The entry of the man into the sea symbolises the death of the old season, leading to a rebirth, witnessed through re-emergence, heralding the new season of work in the marine environment. As Gachihi (2012) noted, rituals carried out by elders related to natural resources reveal symbolism of death and rebirth, depletion and regeneration as well as pollution and purification. These ceremonies are an admission of human limits in regard to the control of natural forces, in spite of knowledge of the same.

Therefore, the ritual behaviour of a community also forms part of the perception and knowledge repertoire as well as scheduling of events that characterise resource use. Activities are scheduled to indicate the start and end of the fishing season as well as entry into the mangrove forests. The fact that the particular place is chosen through tradition and the reason it is chosen is unknown is indicative of the ritual importance of fishing in the community. The specific area in the sea where rituals take place points to the indigenous geographical information systems (GIS), a connection between physical and ritual space through indigenous GIS. The ability to identify particular zones of the sea and to find one's bearings in the midst of the immensity of the sea, out of sight of land, is part of "the cognitive skill set of fishermen" (Maldonado, 2005).

Conclusion

There is a very vibrant knowledge of the marine environment and its resources among the Giriama. This has become refined, and should be allowed space in policy documents and research agenda since its influence can no longer be ignored. For the Giriama, indigenous knowledge about natural resources generally and marine resources in particular, combined with the regulations that are in place for the management of the resource, depict a complex picture of the meeting of culture and nature. The implication is that natural resources do not just belong in the realm of the natural world. Rather, natural resources are connected to the human world through language, ritual, taboo and kinship ties. In a nutshell, the sacredness with which human social relations are treated is extended to the use of natural resources. Nature is sacred; therefore, humans respect and worship the natural, and nature is taken to be part and parcel of their kinship and friendship ecosystem.

This study brings out the contextual, relational and experiential nature of indigenous knowledge among the Giriama in regard to the natural world in general, and marine resources in particular. This indigenous ecological knowledge is not only based on a worldview but also on the culture that respects wholeness, community and harmony which are deeply embedded in beliefs, norms, practices and values. Among the Giriama a person becomes human only in the midst of others and seeks both individual and collective harmony as the primary task in the process of becoming a true person through knowledge, including that of nature and respect for it. Thus, indigenous knowledge of time, space, nature and resources among the Giriama emphasises the practical, interpersonal and social domains of functioning, and they are quite differentiated from the cognitive 'academic' intelligence that dominates Western concepts of the construct.

From this study and other anthropological studies on human/nature interactions, it can be inferred that ecosystems are in part socially constructed, and resource management and conservation practices in indigenous systems are based on a variety of social processes. One facet is concerned with the generation, accumulation and transmission of indigenous knowledge. The second could be about the edifice and dynamic subtleties of institutions, together with control, guidance and regulations that run those institutions. Yet, a third set also needs to be contended with, which is about rituals and ceremonies. These provide the contextual meaning to the cultural processes for the internalisation of indigenous ecological knowledge practices. Cosmology also comes into play, and is concerned with the world view and cultural values of the group in question. Each of the processes is assimilated and fused into a vortex of cultural practices in various places in the world.

Consequently, indigenous knowledge cannot be simply analysed at the level of cerebral activity only as 'knowledge' or 'technique, but also as a knowledge/practice/belief complex in which the context is provided by culture and history. Accordingly, the importance of Traditional Ecological Knowledge (TEK) in the conservation of biodiversity, and as shown in this study, is demonstrable in the sense that one cannot merely learn from traditional techniques of biodiversity conservation outside of their cultural context. Nor can one discuss, in a decontextualised way, the possible contribution of TEK to sustainable land use, environmental assessment or ecological restoration. It is the nature and significance of this indigenous knowledge, developed over millennia, that facilitates navigation of the marine space by the Giriama people, in search of livelihoods, through spiritual harmony between the human world and nature.

References

Acheson J (2003) Capturing the commons: Devising institutions to manage the marine lobster industry. University Press of New England, Lebanon, NH. 264 pp

Alexander A, Van Djik J (1996) Scientific knowledge and indigenous perception of area, weight and space. Indigenous Knowledge and Development Monitor 4 (3): 15-17

Andersen D, Brown C, Walker RJ, Elkin K (2004) Traditional ecological knowledge and contemporary subsistence harvest of non-salmon fish in the Koyukuk River Drainage, Alaska. Technical Paper No. 282. ADF&G, Fairbanks. 165 pp

Balee W (1989) The culture of Amazonian forests. In: Posey DA, Balee, W (eds) Resource management in Amazonia: Indigenous and folk strategies, Volume 7, pp 1-21. The New York Botanical Garden, Bronx, NY. 289 pp

Barth, F (2002) An anthropology of knowledge. Current Anthropology 43 (1): 1-11

Berkes, F (1993) Traditional ecological knowledge in perspective. In: JT Inglis (ed) Traditional ecological knowledge: Concepts and cases, pp 1-9. International Development Research Centre (IDRC), Ottawa. 150 pp

Berkes F (1999) Sacred ecology: Traditional ecological knowledge and resource management. Taylor & Francis, Philadelphia, PA. 209 pp

Berlin B (1975) Folk semantics in relation to biological classification and nomenclature. Annual Review of Ecology and Semantics 4: 259-271

Berlin B (2016) Ethno-biological classification: Principles of categorization of plants and animals in traditional societies. Princeton University Press, Princeton. 335 pp

Callicott JB (1994) Earth's insight: A multicultural survey of ecological ethics from the Mediterranean Basin to the Australian outback. University of California Press, Berkeley, CA. 285 pp

Chilisa B (2012). Indigenous research methodologies. Sage, Los Angeles. 343 pp

Clifton J 2003. Prospects for co-management in Indonesia's marine protected areas, Marine Policy 27: 389-395

Cunha L (1997) Space and territoriality in the world of artisanal fishing. In: Diegues AC (ed) Tradition and social change in the coastal communities of Brazil, pp 48-51. NUPAUB-USP, São Paulo. 122 pp

Diegues AC (2001) Traditional fisheries knowledge and social appropriation of marine resources in Brazil. Paper presented at Mare Conference on People and the Sea, Amsterdam, August/September, 2001. 20 pp

Drew JA (2005) Use of traditional ecological knowledge in marine conservation. Conservation Biology 19 (4): 1286-1293

Ellen, C (1982) Systems and regulation. In: Ellen C (ed) Environment, subsistence and system: The ecology of small-scale social formations, pp 177-203. Cambridge University Press, Cambridge. 120 pp

Fraser, EDG, Dougill A, Mabee W, Reed MS, McAlpine, P (2006) Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. Journal of Environmental Management 78 (2): 114-127

Gachihi RN (2012) Sacred folk healing and conservation of kaya forests, coastal Kenya. MA Thesis, Institute of Anthropology, Gender and African Studies, University of Nairobi. 221 pp

Gyampoh AB, Winston AA (2011). Mapping and documenting indigenous knowledge in climate change adaptation in Ghana. UNDP, New York. 139 pp

Hale LZ, Meltzer E, Ngoile M (1998) Application to international experience of formulation of national policy for coastal management for the Republic of South Africa. Coastal Resource Centre, University of Rhode Island, Narragansett. 89 pp

Hunn E (1975) Cognitive processes in folk ornithology: The identification of gulls. Working Paper 42: 73. Language–Behaviour Research Laboratory, University of California Press, Berkeley. 73 pp

Ihezue L (2007) Developing cultural industries in Nigeria: A case for rural women integration through micro-credit. In: Babawale T (ed) The Place of research and studies in the development of Africa and the African Diaspora, pp 318-331. Centre for Black and African Arts and Civilisation (CBAAC), Lagos. 386 pp

Kuper A (2014) Anthropology and anthropologists: The modern British School. Routledge, New York. 152pp

Majid-Cooke F (2003) Maps and counter-maps: Globalised imaginings and local realities of Sarawak's plantation agriculture. Journal of Southeast Asian Studies 34 (2): 265-284

Maldonado S (2005) Perception and utilization of space in artisanal fishing communities. In: Diegues AC (ed) Tradition and social change in the coastal communities of Brazil, pp 58-63. NUPAUB, São Paulo. 207 pp

Malm T (2009) Women of the coral gardens: The significance of marine gathering in Tonga. Traditional Marine Resource Management and Knowledge Information Bulletin (25): 2-15

Mendoza JD (2000) The condition of indigenous knowledge (IK) from a structurationist perspective. First National Conference on Cordillera Research, Baguio City, Philippines, November 11, 2000

Netting R (1968) Introduction, Hill farmers of Nigeria: A cultural ecology of Kofyar of the Jos au. University of Washington Press, Seattle. 259 pp

Oso PA (2007) Transferability of knowledge in African indigenous herbal healing. In: Babawale T (ed) The Place of research and studies in the development of Africa and the African Diaspora, pp 185-229. Centre for Black and African Arts and Civilisation (CBAAC), Lagos. 386 pp

Posey DA (1985) Nature and Indigenous Guidelines for new Amazonian development strategies: Understanding biological diversity through ethnoecology. In: Hemming J (ed) Man's impact on forests and rivers: Change in the Amazon basin, pp. 156-81. Manchester University Press, Manchester. 232pp

Robbins P (2010) Red-spotted ox: A Pokot life. International Work Group for Indigenous Affairs, Copenhagen. 337 pp

Ruddle K (2000) Systems of knowledge: Dialogue, relationships and process. Environment, Development and Sustainability 2: 277-304

Sirait MT, Prasodjo S, Podger N, Flavelle A, Fox J (1994) Mapping customary land in East Kalimantan, Indonesia: A tool for forest management. Ambio 23: 411-417

Shilabukha DK (2000) The role of indigenous knowledge in the management of mangrove bio-diversity in Msambweni Division of Kwale District–Kenya. Unpublished MA Thesis, Institute of African Studies, University of Nairobi. 103 pp

Shilabukha K (2007) Indigenous knowledge, biodiversity, technology and economic values: Rethinking the link. In: Babawale T (ed) The Place of research and studies in the development of Africa and the African Diaspora, pp 171-184. Centre for Black and African Arts and Civilisation (CBAAC), Lagos. 386 pp

Steward JH (1958) Theory of culture change: The methodology of multi-linear evolution. University of Illinois Press, Chicago. 244 pp

UNICED (1987) Our common future: Report of the World Commission on Environment and Development. United Nations, New York. 300 pp

Wagner GP, da Silva A (2014) Pre-historic maritime and Brazilian shellmounts. Archaeological Discovery 2 (1): 1-5

Warren DM, Slikkerveer J, Brokensha D (eds) (1995) The cultural dimension of development: Indigenous knowledge systems. Intermediate Technology Publications, London. 582 pp

Wavey CR (1993) International Workshop on Indigenous Knowledge and Community-based Resource Management: Keynote Address. In: Inglis JT (ed) Traditional ecological knowledge: Concepts and cases, pp 11-16. International Program on Traditional Ecological Knowledge and International Development Research Centre, Ottawa, Ontario. 150 pp

Williams NM, Baines G (eds) (1993) Traditional ecological knowledge: Wisdom for sustainable development. Centre for Resource and Environmental Studies, National University of Australia, Canberra. 185 pp

Willis RG (1990) Introduction. In: Willis RG (ed) Signifying animals: Human meaning in the natural world, pp 1-24. Unwin Hyman, London. 258 pp

Zavarin E (1991) Comment on the medicinal value of tropical ecosystems. In: Kingsley D, Bernstan MS (eds) Resources environment and population: Present knowledge, future options, pp 252-253. Oxford University Press, New York. 440 pp

Reef fishes of praia do Tofo and praia da Barra, Inhambane, Mozambique

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Abstract

The coral reefs around Praia do Tofo and Praia da Barra, southern Mozambique, are known for their aggregations of marine megafauna, but no studies have yet examined their reef fish biodiversity. This study assesses for the first time the ichthyofaunal diversity of the seas around Praia do Tofo and Praia da Barra. Methods involved underwater observations during recreational dives between February and September 2016, and the use of photographic records from 2015 and 2016. A total of 353 species, representing 79 families, were recorded from 16 patch reefs in the region. The area shows comparable species diversity to protected areas in the southwestern Indian Ocean and has a high proportion of carnivores, together hinting at these reefs being in good condition. However, high primary productivity driven by coastal upwelling may be significantly influencing fish diversity and trophic structure, making these metrics unreliable measures of reef health in this instance. Future studies investigating the sustainability of this ecosystem would benefit from utilising a wide range of reef health measures.

Keywords: Icthyofaunal diversity, Mozambique, checklist, underwater census

Introduction

The ecotourism industry of the Inhambane province in southern Mozambique accounts for approximately 7% of the province's annual income (Mutimucuio & Meyer, 2011). The primary tourism hotspots are the Bazaruto Archipelago National Park (BANP) and the southern area around the Inhambane peninsula. In the latter, the seas around Praia do Tofo and Praia da Barra (hereafter referred to as PTPB) are particularly important due to their resident populations of manta rays and whale sharks (Pierce *et al.*, 2010; Tibirica *et al.*, 2011). Venables *et al.* (2016) estimate that manta ray tourism alone contributes $34 million USD per annum to the province's economy. Scientific research in the PTPB area has thus predominantly focused on these charismatic species (e.g. Rohner *et al.*, 2013; 2014); so far, very little research has been conducted on the biodiversity of resident fish populations. This aspect of the PTPB's marine ecosystem is expected to gain value in the future, as has occurred in the BANP (Schleyer & Celliers, 2005), due to the continued decline of local megafauna populations (Rohner *et al.*, 2013). As of 2014, the United Nations and World Heritage Convention (2014) recommend that the protected area currently represented by the BANP be extended south to include the seas around PTPB. Knowledge of the fish biodiversity of this area will help support this recommendation.

Species richness information is currently missing from the PTPB seas but this data is vital for future ecosystem management. Biodiversity data is necessary to identify key biological components (Pereira, 2000), provide a baseline from which ecosystem stability and function can be assessed (Cleland, 2011), and to predict the effects of biodiversity loss on ecosystem provision (Bellwood & Hughes, 2001; Gillibrand *et al.*, 2007; Maggs *et al.*, 2010). The PTPB area is bordered by the tropical and sub-tropical latitudes of the southwestern Indian Ocean and are home to a number of different reef habitats likely to support diverse reef fish assemblages. The most common habitats are deepwater, offshore patch reefs which are characteristic of southern Mozambique and typically have low levels of coral cover (Pereira, 2000; Motta *et al.*, 2002; Schleyer & Celliers, 2005). Other marine ecosystems in the region include mangrove swamps, estuarine reefs and shallow inshore fringing reefs. This range of reef and coastal environments provides substantial habitat and nursery grounds for fish species in the area. The PTPB area has a relatively large associated human population of over 250,000 people (Instituto Nacional de Estatística, 2007), based primarily in the cities of Maxixe and Inhambane (Fig. 1). However, there is little to no management in place to safeguard the marine ecosystems and the services they provide. This study constitutes a baseline assessment of fish diversity of the reefs surrounding Praia do Tofo and Praia da Barra, and highlights the need for further investigations into the state of these ecosystems.

Materials and Methods

Study Site

Praia do Tofo (23° 51.205' S; 35° 32.882' E) and Praia da Barra (23° 47.541' S; 35° 31.142' E) harbour a number of shallow fringing coral reefs. However, many of the

Figure 1. Map of the study area and its location along the coast of Mozambique (inset). Sampled reefs are indicated by (•); their broad characteristics are described in Table 1.

Table 1. Names and descriptions of sampled reefs, including the underwater survey method used and the amount of time spent surveying each location.

Site Name (Number)	Site Description	Sampling Method	Sampling Time (mins)
Amazon (1)	Offshore, horseshoe reef with an abundance of azooxanthellate soft corals; 23 – 28 metres.	SCUBA	87
Hospital (2)	Offshore, southward sloping reef with occasional short pinnacles; 24 – 26 metres.	SCUBA	80
The Office (3)	Topographically complex offshore reef with an abundance of overhangs and valleys with many encrusting soft corals; 22 – 26 metres.	SCUBA	177
Reggie's (4)	Tall, offshore reef rising between 4 – 8 metres from the seafloor; reef crests are dominated by large colonies of *Tubastrea micranthus*; 22 – 30 metres.	SCUBA	231
Buddies (5)	Shallow, inshore reef subject to persistent swell and fishing pressure; 8 – 10 metres.	SCUBA	97
The Wall (6)	Shallow estuarine reef with daily exposure to strong tidal currents; a combination of seagrass, rocky reef and sand patch microhabitats; 0-4 metres.	Snorkel	70
Mike's Cupboard (7)	Submerged sand dune reef, with many potholes and gullies surrounded by sandy reef flats; 12 – 16 metres.	SCUBA	108
Salon (8)	Shallow inshore reef composed of multiple large pinnacles surrounded by sandy bottom; subject to high turbidity from wave action; 10-14 metres.	SCUBA	175
Sherwood Forest (9)	Offshore reef just outside of Tofo bay, made of one large and one smaller pinnacle both supporting large populations of *Tubastrea micranthus*; 22 – 26 metres	SCUBA	58
Giants Castle (10)	Straight north-south reef with an extensive reef flat and deep reef wall; known within the local dive industry as having the best sighting rate for marine megafauna; 27 – 32 metres.	SCUBA	214
Marble Arch (11)	Inshore reef exposed to minor wave action; large reef flat with a few large potholes and one large rock arch; 14 – 18 metres.	SCUBA	51
Rob's Bottom (12)	Very patchy eastward sloping reef that is often subject to high current with high algal cover; 23 – 27 metres.	SCUBA	158
Manta Reef (13)	A large offshore reef, with a large central reef flat; peripheries are characterised by short, steep reef slopes with a number of tall pinnacles; 18 – 24 metres	SCUBA	365
Outback (14)	Similar reef shape as Giant's Castle, yet with more small inlets that house a number of deep overhangs and archways; 25 – 30 metres.	SCUBA	76
Coconut Bay (15)	Shallow inshore rocky reef with small patches of encrusting soft coral and larger swathes of seagrass; 4 – 8 metres.	Snorkel	53
Paindane Coral Gardens (16)	Small, shallow reef protected from offshore waves by a barrier rock extending from shore; the most abundant coral community in this area, dominated by *Sinularia* spp. soft coral and corymbose acroporids; 1 – 6 metres.	Snorkel	182

sites frequented by the local dive industry are in deeper waters to the north and south. In this study, diversity was recorded on reefs spanning approximately 40 km along the coast of the Inhambane province (Fig. 1). A total of 16 reef sites between 1 and 32 m (Table 1) were surveyed between February and September 2016.

Sampling

The primary method used was underwater observations during a random swim. Species were identified *in situ* if possible and recorded on an underwater PVC slate. If required, a photograph was taken for subsequent species identification. Deep sites (> 8 m) were surveyed using SCUBA, as part of a recreational dive charter operated by Peri-Peri Divers. Shallow sites were assessed by snorkelling. Fifty-four individual surveys, totalling 2218 minutes of observation time were undertaken (total surveying times for each site are shown in Table 1). The species richness recorded from underwater observations was supplemented through the inclusion of species that had been sighted in the year preceding the survey period, and for which there was photographic evidence available from local ecotourism and dive operators (e.g. *Mola mola*). Solicited data from outside the study period was utilised to ensure that rare or seasonally restricted species were recorded. Data collection was approved by the Maritime Administration of the City of Inhambane, and the Ministry of Justice.

Estimated richness and regional comparisons

To determine the number of conspicuous species missed during the visual census, the Coral Fish Diversity Index (CFDI) developed by Allen & Werner (2002) was calculated and compared to the recorded species richness (SR_{obs}). The CFDI examines the diversity of six common and easily observable families as representatives of reef fish species richness. These families are Acanthuridae, Chaetodontidae, Labridae, Pomacanthidae, Pomacentridae and Scaridae. Taxonomic research has suggested that Scaridae be reclassified as a sub-family of Labridae, named Scarinae (Westneat & Alfaro, 2005); however, for the purposes of the present analysis this has no influence on the value of the CFDI. In areas < 2000 km^2, a theoretical species richness (SR_{theor}) is then generated using the equation $SR_{theor} = 3.39(CFDI) – 20.595$ (Allen & Werner, 2002). SR_{theor} was calculated for other reef systems in the southwestern Indian Ocean, using published literature, to draw loose comparisons between the richness of these areas and that observed in the current study (as in Wickel *et al.*, 2014).

Estimating trophic structure

The dietary preference of each species was determined using classifications by Harmelin-Vivien (1979), Hiatt & Strasburg (1960), Hobson (1974), Myers (1999), and FishBase (http://fishbase.org). Where information on a species' feeding habit was not available, feeding habit was assumed from those of congener species and labelled in Table 2 with a '*'. Where congeners were not available the feeding habit was labelled 'unknown' (NA). Eight trophic categories were used, as in Gillibrand *et al.* (2007), Chabanet & Durville (2005), and Durville *et al.* (2003). Trophic categories included herbivore, omnivore, browser of sessile invertebrates, diurnal carnivore, nocturnal carnivore, piscivore, diurnal planktivore, and nocturnal planktivore. The trophic categories, excluding herbivores and omnivores, were then grouped into general carnivores *sensu lato*.

Results

A total of 353 species, representing 79 families, were recorded in the current study from 328 visual observations and 25 past photographic records (Table 2). Of the total number of species recorded, 27 were cartilaginous fish and 326 were bony fish. The CFDI-generated SR_{theor} was 329, lower than the observed species richness (Table 3).

Twelve families represented over half of the total recorded diversity, these included Acanthuridae (17), Balistidae (11), Carangidae (10), Chaetodontidae (18), Holocentridae (10), Labridae (32), Lutjanidae (12), Muraenidae (14), Pomacentridae (21), Scorpaenidae (13), Serranidae (19), and Tetraodontidae (10). Nearly half the recorded families (48%) were represented by one species only. Five of these families are monospecific including, Rachycentridae, Rhincodontidae, Rhinidae, Stegostomatidae, and Zanclidae. The most species-rich genera were *Chaetodon* (12), *Epinephelus* (10) and *Gymnothorax* (10).

General carnivores comprised 78% of the species composition (Fig. 2; Table 4). Seventeen of the species' feeding habits were assumed from those of congener species whilst fifteen were labelled as 'unknown'. The largest single trophic group, the diurnal carnivores, comprised 27% of the species composition (Fig. 2) and included predominantly labrids. The most common nocturnal carnivore families were the lutjanids, the muraenids and the serranids. Chaetodontids made up the majority of the browsers of sessile invertebrates, whilst acanthurids and scarids represented most of the herbivores. There were no other notably common families dominating other trophic groups.

Table 2. Reef fish species checklist from the PTPB area of Mozambique, sighted through surveys (S) and photographic records (P). Where a species' trophic category has been assumed from a congener species, it is labelled with a '*'.

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
ACANTHURIDAE		
Acanthurus dussumieri Cuvier and Valenciennes, 1835	S	H
Acanthurus leucosternon Bennett, 1833	S	H
Acanthurus lineatus Linnaeus, 1758	S	H
Acanthurus nigrofuscus Forsskål, 1775	S	H
Acanthurus tennentii Günther, 1861	S	H
Acanthurus triostegus Linnaeus, 1758	S	H
Acanthurus xanthopterus Valenciennes, 1835	S	H
Ctenochaetus binotatus Randall, 1955	S	H
Ctenochaetus striatus Quoy and Gaimard, 1825	S	H
Ctenochaetus truncates Randall and Clements, 2001	S	H
Naso brachycentron Valenciennes, 1835	S	H
Naso brevirostris Cuvier, 1829	S	H
Naso elegans Rüppell, 1829	S	H
Paracanthurus hepatus Linné, 1766	S	DPL
Zebrasoma desjardinii Bennett, 1836	S	H
Zebrasoma gemmatum Valenciennes, 1835	S	H
Zebrasoma scopas Cuvier, 1829	S	H
AMBASSIDAE		
Ambassis natalensis Gilchrist and Thompson, 1908	S	DC
ANTENNARIIDAE		
Antennarius coccineus Lesson, 1831	S	Pi
Antennarius commerson Lacepède, 1798	S	Pi
Antennarius nummifer Cuvier, 1817	P	Pi
APOGONIDAE		
Cheilodipterus quinquelineatus Cuvier, 1828	S	NC
Ostorhinchus angustatus Smith and Radcliffe, 1911	S	BSI
Ostorhinchus flagelliferus Smith, 1961	S	BSI
Ostorhinchus fleurieu Lacepède, 1802	S	BSI*
Pristiapogon kallopterus Bleeker, 1856	S	NC
Taeniamia mozambiquensis Smith, 1961	S	NA
ATHERINIDAE		
Atherinomorus lacunosus Forster, 1801	S	NPL

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
AULOSTOMIDAE		
Aulostomus chinensis Linnaeus, 1766	S	Pi
BALISTIDAE		
Balistapus undulatus Park, 1797	S	DC
Balistoides conspicillum Bloch and Schneider, 1801	S	DC
Balistoides viridescens Bloch and Schneider, 1801	S	DC
Odonus niger Rüppell, 1836	S	DC
Pseudobalistes flavimarginatus Rüppell, 1829	P	DC
Pseudobalistes fuscus Bloch and Schneider, 1801	S	DC
Rhinecanthus aculeatus Linnaeus, 1758	S	DC
Rhinecanthus rectangulus Bloch and Schneider, 1801	S	O
Sufflamen bursa Bloch and Schneider, 1801	S	DC
Sufflamen fraenatum Latreille, 1804	S	DC
Xanthichthys lineopunctatus Hollard, 1854	S	DC*
BLENNIIDAE		
Aspidontus dussumieri Valenciennes, 1836	S	H
Aspidontus taeniatus Quoy and Gaimard, 1834	S	DC
Aspidontus tractus Fowler, 1903	S	DC
Cirripectes stigmaticus Strasburg and Schultz, 1953	S	H
Ecsenius midas Starck, 1969	S	H
Istiblennius edentulous Forster and Schneider, 1801	S	H
Plagiotremus rhinorhynchos Bleeker, 1852	S	NPL
Plagiotremus tapeinosoma Bleeker, 1857	S	O
BOTHIDAE		
Bothus mancus Broussonet, 1782	S	DC
Bothus pantherinus Rüppell, 1830	S	NC
CAESIONIDAE		
Caesio varilineata Carpenter, 1987	S	DPL
Caesio xanthalytos Holleman *et al.* 2013	S	DPL*
Caesio xanthonata Bleeker, 1853	S	DPL
Pterocaesio marri Schultz *et al.*, 1953	S	DPL
Pterocaesio tile Cuvier and Valenciennes, 1830	S	DPL
CALLIONMYIDAE		
Neosynchiropus stellatus Smith, 1963	S	DC

FAMILIES Species - Authors	Sighting Record	Trophic Category
CARANGIDAE		
Alectis ciliaris Bloch, 1787	P	DC
Alectis indica Rüppell, 1830	P	DC
Caranx bucculentus Alleyne and Macleay, 1877	S	DC
Caranx heberi Bennett, 1830	S	DC
Caranx ignobilis Forsskål, 1775	S	DC
Caranx melampygus Cuvier, 1833	S	DC
Caranx sexfasciatus Quoy and Gaimard, 1825	S	Pi
Elagatis bipinnulata Quoy and Gaimard, 1825	S	DC
Gnathanodon speciosus Forsskål, 1775	S	DC
Seriola lalandi Valenciennes, 1833	S	DC
CARCHARHINIDAE		
Carcharhinus amblyrhynchos Bleeker, 1856	S	Pi
Carcharhinus leucas Müller and Henle, 1839	P	DC
Carcharhinus limbatus Müller and Henle, 1839	S	Pi
Carcharhinus melanopterus Quoy and Gaimard, 1824	S	Pi
Carcharhinus obscurus Lesueur, 1818	S	DC
Triaenodon obesus Rüppell, 1837	S	DC
CENTRISCIDAE		
Aeoliscus strigatus Günther, 1861	P	DC
CHAETODONTIDAE		
Chaetodon auriga Forsskål, 1775	S	BSI
Chaetodon blackburnii Desjardins, 1836	S	BSI
Chaetodon dolosus Ahl, 1923	S	BSI
Chaetodon guttatissimus Bennett, 1833	S	BSI
Chaetodon interruptus Ahl, 1923	S	BSI
Chaetodon kleinii Bloch, 1790	S	BSI
Chaetodon lineolatus Cuvier, 1831	S	BSI
Chaetodon lunula Lacepède, 1802	S	BSI
Chaetodon madagaskariensis Ahl, 1923	S	BSI
Chaetodon melannotus Bloch and Schneider, 1801	S	BSI
Chaetodon meyeri Bloch and Schneider, 1801	S	BSI
Chaetodon trifascialis Quoy and Gaimard, 1825	S	BSI
Chaetodon xanthurus Bleeker, 1857	S	BSI

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Forcipiger flavissimus Jordan and McGregor, 1898	S	BSI
Hemitaurichthys zoster Bennett, 1831	S	DPL
Heniochus acuminatus Linnaeus, 1758	S	BSI
Heniochus diphreutes Jordan, 1903	S	DPL
Heniochus monoceros Cuvier, 1831	S	BSI
CIRRHITIDAE		
Cirrhitichthys oxycephalus Bleeker, 1855	S	DC
Cyprinocirrhites polyactis Bleeker, 1874	S	DPL
Oxycirrhites typus Bleeker, 1857	P	DPL
Paracirrhites arcatus Cuvier, 1829	S	DC
Paracirrhites forsteri Schneider, 1801	S	DC
CLINIDAE		
Clinus venustris Gilchrist and Thompson, 1908	S	NA
Pavoclinus laurentii Gilchrist and Thompson, 1908	S	NA
CLUPEIDAE		
Gilchristella aestuaria Gilchrist, 1913	S	DPL
CONGRIDAE		
Heteroconger hassi Klausewitz and Eibl-Eibesfeldt, 1959	S	NC
DACTYLOPTERIDAE		
Dactyloptena orientalis Cuvier, 1829	S	NC
DASYATIDAE		
Dasyatis microps Annandale, 1908	S	NC*
Himantura jenkinsii Annandale, 1909	S	NC
Himantura uarnak Gmelin, 1789	S	NC
Neotrygon kuhlii Müller and Henle, 1841	S	NC
Taeniura lymma Forsskål, 1775	P	NC
Taeniura meyeni Müller and Henle, 1841	S	NC
DIODONTIDAE		
Diodon holocanthus Linnaeus, 1758	S	NC
Diodon hystrix Linnaeus, 1758	S	NC
Diodon liturosus Shaw, 1804	S	NC
ECHENEIDAE		
Echeneis naucrates Linnaeus, 1758	S	NC
ENGRAULIDAE		
Thryssa vitrirostris Gilchrist and Thompson, 1908	S	DPL

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
EPHIPPIDAE		
Platax teira Forsskål, 1775	S	O
FISTULARIIDAE		
Fistularia commersonii Rüppell, 1838	S	Pi
GERREIDAE		
Gerres longirostris Lacepède, 1801	S	DC
GINGLYMOSTOMATIDAE		
Nebrius ferrugineus Lesson, 1831	P	NC
GOBIIDAE		
Amblyeleotris steinitzi Klausewitz, 1974	S	DC
Amblyeleotris wheeleri Polunin and Lubbock, 1977	S	DC*
Caffrogobius saldanha Barnard, 1927	S	NA
Valenciennea strigata Broussonet, 1782	S	DC
HAEMULIDAE		
Diagramma pictum Thunberg, 1792	S	DC
Plectorhinchus flavomaculatus Cuvier, 1830	S	NC
Plectorhinchus gaterinus Forsskål, 1775	S	NC
Plectorhinchus playfairi Pellegrin, 1914	S	DC
Plectorhinchus vittatus Linnaeus, 1758	S	NC
HEMIRAMPHIDAE		
Hyporhamphus affinis Günther, 1866	S	O
HOLOCENTRIDAE		
Myripristis adusta Bleeker, 1853	S	NPL
Myripristis berndti Jordan and Evermann, 1903	S	NC
Myripristis botche Cuvier, 1829	S	NC
Myripristis murdjan Forsskål, 1775	S	NPL
Myripristis vittata Valenciennes, 1831	S	NPL
Neoniphon samara Forsskål, 1775	S	NC
Pagellus natalensis Steindachner, 1903	S	O
Sargocentron caudimaculatum Rüppell, 1838	S	NC
Sargocentron diadema Lacepède, 1802	S	NC
Sargocentron spiniferum Forsskål, 1775	S	NC
ISTIOPHORIDAE		
Istiompax indica Cuvier, 1832	S	Pi
Istiophorus platypterus Shaw, 1792	P	Pi

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Makaira nigricans Lacepède, 1802	P	Pi
KYPHOSIDAE		
Kyphosus vaigiensis Quoy and Gaimard, 1825	S	H
LABRIDAE		
Anampses meleagrides Valenciennes, 1840	S	DC
Bodianus anthioides Bennett, 1832	S	DC
Bodianus axillaris Bennett, 1832	S	DC
Bodianus diana Lacepède, 1801	S	DC
Bodianus trilineatus Fowler, 1934	S	DC*
Anampses twistii Bleeker, 1856	S	DC
Cheilinus trilobatus Lacepède, 1801	S	DC
Cheilinus undulates Rüppell, 1835	S	DC
Cheilio inermis Forsskål, 1775	S	DC
Coris aygula Lacepède, 1801	S	DC
Coris caudimacula Quoy and Gaimard, 1834	S	DC
Coris cuvieri Bennett, 1831	S	DC
Coris formosa Bennett, 1830	S	DC
Gomphosus caeruleus Lacepède, 1801	S	DC
Gomphosus varius Lacepède, 1801	S	DC
Halichoeres cosmetus Randall and Smith, 1982	S	DC
Halichoeres hortulanus Lacepède, 1801	S	DC
Halichoeres iridis Randall and Smith, 1982	S	DC
Halichoeres lapillus Smith, 1947	S	DC
Halichoeres nebulosus Valenciennes, 1839	S	DC
Halichoeres scapularis Bennett, 1832	S	DC
Halichoeres zeylonicus Bennett, 1833	S	DC
Halichoeres zulu Randall and King, 2010	S	DC
Labroides bicolor Fowler and Bean, 1928	S	DC
Labroides dimidiatus Valenciennes, 1839	S	DC
Macropharyngodon bipartitus Smith, 1957	S	DC
Macropharyngodon cyanoguttatus Randall, 1978	S	DC*
Novaculichthys taeniourus Lacepède, 1801	S	DC
Pseudocoris heteroptera Bleeker, 1857	S	DC
Thalassoma amblycephalum Bleeker, 1856	S	DC

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Thalassoma hebraicum Lacepède, 1801	S	DC
Thalassoma lunare Linnaeus, 1758	S	DC
LUTJANIDAE		
Aprion virescens Valenciennes, 1830	S	Pi
Lutjanus ehrenbergii Peters, 1869	S	NC
Lutjanus fulviflamma Forsskål, 1775	S	NC
Lutjanus gibbus Forsskål, 1775	S	NC
Lutjanus kasmira Forsskål, 1775	S	NC
Lutjanus lutjanus Bloch, 1790	S	NC
Lutjanus monostigma Cuvier, 1828	S	NC
Lutjanus notatus Cuvier, 1828	S	NC
Lutjanus rivulatus Cuvier, 1828	S	NC
Lutjanus sebae Cuvier, 1816	S	NC
Macolor niger Forsskål, 1775	S	NC
Paracaesio sordida Abe and Shinohara, 1962	S	DPL
MALACANTHIDAE		
Malacanthus brevirostris Guichenot, 1848	S	DC
MICRODESMIDAE		
Nemateleotris magnifica Fowler, 1938	S	NPL
Ptereleotris evides Jordan and Hubbs, 1925	S	NPL
Ptereleotris heteroptera Bleeker, 1855	S	DPL
MOLIDAE		
Mola mola Linnaeus, 1758	P	DC
MONACANTHIDAE		
Aluterus scriptus Osbeck, 1765	S	O
Acreichthys tomentosus Linnaeus, 1758	S	DC
Cantherhines fronticinctus Günther, 1867	S	BSI
Cantherhines pardalis Rüppell, 1837	S	BSI
Pervagor janthinosoma Bleeker, 1854	S	NA
Stephanolepis auratus Castelnau, 1861	S	NA
MONOCENTRIDAE		
Cleidopus gloriamaris De Vis, 1882	P	NA
MONODACTYLIDAE		
Monodactylus argenteus Linnaeus, 1758	S	DPL

FAMILIES Species - Authors	Sighting Record	Trophic Category
MULLIDAE		
Mulloidichthys ayliffe Uiblein, 2011	S	NC
Mulloidichthys flavolineatus Lacepède, 1801	S	NC
Mulloidichthys vanicolensis Valenciennes, 1831	S	NC
Parupeneus barberinus Lacepède, 1801	S	DC
Parupeneus indicus Shaw, 1803	S	DC
Parupeneus macronemus Lacepède, 1801	S	DC
Parupeneus trifasciatus Lacepède, 1801	S	DC
MURAENIDAE		
Echidna nebulosa Ahl, 1789	S	NC
Enchelycore pardalis Temminck and Schlegel, 1846	S	Pi
Gymnomuraena zebra Shaw, 1797	S	NC
Gymnothorax breedeni McCosker and Randall, 1977	S	NC
Gymnothorax eurostus Abbott, 1860	S	NC
Gymnothorax favagineus Bloch and Schneider, 1801	S	NC
Gymnothorax flavimarginatus Rüppell, 1830	S	Pi
Gymnothorax griseus Lacepède, 1803	S	NC*
Gymnothorax javanicus Bleeker, 1859	S	NC
Gymnothorax meleagris Shaw, 1795	S	DC
Gymnothorax miliaris Kaup, 1856	S	DC
Gymnothorax nudivomer Günther, 1867	S	NC*
Gymnothorax undulates Lacepède, 1803	S	NC
Rhinomuraena quaesita Garman, 1888	P	Pi
MYLIOBATIDAE		
Aetobatus narinari Euphrasen, 1790	P	DC
Manta alfredi Krefft, 1868	S	DPL
Manta birostris Walbaum, 1792	S	DPL
Mobula japonica Müller and Henle, 1841	S	DPL
ODONTASIPSIDAE		
Carcharias taurus Rafinesque, 1810	S	DC
OPHICHTHIDAE		
Myrichthys colubrinus Boddaert, 1781	S	NC
Myrichthys maculosus Cuvier, 1816	S	NC
Pisodonophis cancrivorus Richardson, 1848	P	NC

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
OPLEGNATHIDAE		
Oplegnathus robinsoni Regan, 1916	S	O
OSTRACIIDAE		
Lactoria fornasini Bianconi, 1846	S	BSI*
Lactoria cornuta Linnaeus, 1758	S	BSI
Ostracion cubicus Linnaeus, 1758	S	BSI
Ostracion meleagris Shaw, 1796	S	BSI
PEGASIDAE		
Eurypegasus draconis Linnaeus, 1766	S	BSI
PEMPHERIDAE		
Parapriacanthus ransonneti Steindachner, 1870	S	NPL
Pempheris schwenkii Bleeker, 1855	S	NPL
PINGUIPEDIDAE		
Parapercis schauinslandii Steindachner, 1900	S	DC
PLATYCEPHALIDAE		
Papilloculiceps longiceps Cuvier, 1829	S	DC
PLOTOSIDAE		
Plotosus lineatus Thunberg, 1787	S	NC
POMACANTHIDAE		
Apolemichthys trimaculatus Cuvier, 1831	S	O
Centropyge acanthops Norman, 1922	S	O
Centropyge bispinosa Günther, 1860	S	O
Centropyge multispinis Playfair, 1867	S	O
Pomacanthus chrysurus Cuvier, 1831	S	O
Pomacanthus imperator Bloch, 1787	S	O
Pomacanthus rhomboides Gilchrist and Thompson, 1908	S	O*
Pomacanthus semicirculatus Cuvier, 1831	S	BSI
Pygoplites diacanthus Boddaert, 1772	S	BSI
POMACENTRIDAE		
Abudefduf natalensis Hensley and Randall, 1983	S	O
Abudefduf sexfasciatus Lacepède, 1801	S	O
Abudefduf vaigiensis Quoy and Gaimard, 1825	S	O
Amphiprion allardi Klausewitz, 1970	S	O
Amphiprion perideraion Bleeker, 1855	S	O*

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Chromis fieldi Randall and DiBattista, 2013	S	DPL
Chromis nigrura Smith, 1960	S	DPL
Chromis opercularis Günther, 1867	S	DPL
Chromis viridis Cuvier, 1830	S	O
Chromis weberi Fowler and Bean, 1928	S	DPL
Chrysiptera brownriggii Bennett, 1828	S	O
Chrysiptera unimaculata Cuvier, 1830	S	O
Dascyllus aruanus Linnaeus, 1758	S	DPL
Dascyllus carneus Fischer, 1885	S	O
Dascyllus trimaculatus Rüppell, 1829	S	DPL
Neopomacentrus cyanomos Bleeker, 1856	S	NA
Plectroglyphidodon dickii Liénard, 1839	S	O
Pomacentrus caeruleus Quoy and Gaimard, 1825	S	O
Pomacentrus pavo Bloch, 1787	S	O
Stegastes fasciolatus Ogilby, 1889	S	H
Stegastes pelicieri Allen and Emery, 1985	S	H
PRIACANTHIDAE		
Priacanthus hamrur Forsskål, 1775	S	NC
PSEUDOCHROMIDAE		
Pseudochromis dutoiti Smith, 1955	S	DC
RACHYCENTRIDAE		
Rachycentron canadum Linnaeus, 1766	S	DC
RHINCODONTIDAE		
Rhincodon typus Smith, 1828	S	DPL
RHINIDAE		
Rhina ancylostoma Bloch and Schneider, 1801	P	NC
RHINOBATIDAE		
Rhinobatus annulatus Müller and Henle, 1841	P	NC
Rhinobatus leucospilus Norman, 1926	S	NC
Rhynchobatus djiddensis Forsskål, 1775	S	NC
SCARIDAE		
Chlorurus cyanescens Valenciennes, 1840	S	H
Chlorurus sordidus Forsskål, 1775	S	H
Scarus ghobban Forsskål, 1775	S	H

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Scarus rubroviolaceus Bleeker, 1847	S	H
Scarus scaber Valenciennes, 1840	S	H
Scarus tricolor Bleeker, 1847	S	H
SCOMBRIDAE		
Euthynnus affinis Cantor, 1849	S	DC
Gymnosarda unicolor Rüppell, 1836	S	Pi
Katsuwonus pelamis Linnaeus, 1758	S	DC
Scomberomorus commerson Lacepède, 1801	S	Pi
Scomberomorus plurilineatus Fourmanoir, 1966	P	Pi
Thunnus albacares Bonnaterre, 1788	S	DC
SCORPAENIDAE		
Caracanthus maculatus Gray, 1831	S	NA
Dendrochirus brachypterus Cuvier, 1829	S	NC
Dendrochirus zebra Cuvier, 1829	S	NC
Parascorpaena mossambica Peters, 1855	S	NA
Pterois antennata Bloch, 1787	S	DC
Pterois miles Bennett, 1828	S	Pi
Rhinopias eschmeyeri Condé, 1977	P	Pi*
Rhinopias frondosa Günther, 1892	P	Pi
Scorpaenopsis diabolus Cuvier, 1829	S	Pi
Scorpaenopsis oxycephala Bleeker, 1849	S	Pi
Scorpaenopsis venosa Cuvier, 1829	S	DC
Sebastapistes cyanostigma Bleeker, 1856	S	NA
Taenianotus triacanthus Lacepède, 1802	S	DC
SERRANIDAE		
Cephalopholis argus Schneider, 1801	S	Pi
Cephalopholis miniata Forsskål, 1775	S	NC
Cephalopholis sonnerati Valenciennces, 1828	S	NC
Epinephelus chlorostigma Valenciennes, 1828	S	NC
Epinephelus fasciatus Forsskål, 1775	S	NC
Epinephelus flavocaeruleus Lacepède, 1802	P	Pi
Epinephelus lanceolatus Bloch, 1790	P	NC
Epinephelus macrospilos Bleeker, 1855	S	DC
Epinephelus malabaricus Bloch and Schneider, 1801	S	NC

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Epinephelus merra Bloch, 1793	S	Pi
Epinephelus rivulatus Valenciennes, 1830	S	Pi
Epinephelus tauvina Forsskål, 1775	S	Pi
Epinephelus tukula Morgans, 1959	S	NC
Grammistes sexlineatus Thunberg, 1792	S	NC
Nemanthias carberryi Smith, 1954	S	DPL
Plectropomus punctatus Quoy and Gaimard, 1824	S	Pi
Pogonoperca punctata Valenciennes, 1830	S	NC*
Pseudanthias evansi Smith, 1954	S	DPL
Pseudanthias squamipinnus Peters, 1855	S	DPL
SIGANIDAE		
Siganus luridus Rüppell, 1829	S	H
Siganus sutor Valenciennes, 1835	S	H
SOLEIDAE		
Solea turbynei Gilchrist, 1904	S	NA
SPARIDAE		
Chrysoblephus puniceus Gilchrist and Thompson, 1908	S	DC
Diplodus hottentotus Smith, 1844	S	DC
SPHRYNIDAE		
Sphyrna lewini Griffith and Smith, 1834	S	DC
SPHYRAENIDAE		
Sphyraena putnamae Jordan and Seale, 1905	S	NC
STEGOSTOMATIDAE		
Stegostoma fasciatum Hermann, 1783	S	NC
SYNANCEIIDAE		
Synanceia verrucosa Bloch and Schneider, 1801	S	Pi
SYNGNATHIDAE		
Corythoichthys intestinalis Ramsay, 1881	P	DC
Doryrhamphus dactyliophorus Bleeker, 1853	S	DPL
Hippocampus borboniensis Duméril, 1870	S	DPL*
Hippocampus camelopardalis Bianconi, 1854	P	DPL*
Hippocampus histrix Kaup, 1856	S	DPL
Hippocampus kuda Bleeker, 1852	S	DPL
Solenostomus cyanopterus Bleeker, 1854	S	DC

FAMILIES **Species - Authors**	**Sighting Record**	**Trophic Category**
Trachyrhamphus bicoarctatus Bleeker, 1857	S	NA
SYNODONTIDAE		
Synodus dermatogenys Fowler, 1912	S	Pi
Synodus jaculum Russell and Cressey, 1979	S	Pi
TETRAODONTIDAE		
Arothron hispidus Linnaeus, 1758	S	NC
Arothron meleagris Anonymous, 1798	S	NC
Arothron nigropunctatus Bloch and Schneider, 1801	S	NC
Arothron stellatus Anonymous, 1798	S	NC
Canthigaster amboinensis Bleeker, 1864	S	H
Canthigaster bennetti Bleeker, 1854	S	O
Canthigaster janthinoptera Bleeker, 1855	S	O
Canthigaster smithae Allen and Randall, 1977	S	O*
Canthigaster solandri Richardson, 1845	S	O
Canthigaster valentine Bleeker, 1853	S	O
TETRAROGIDAE		
Ablabys binotatus Peters, 1855	S	NA
Ablabys macracanthus Bleeker, 1852	S	NA
TORPEDINIDAE		
Torpedo marmorata Risso, 1810	S	Pi
Torpedo spp.	S	Pi
ZANCLIDAE		
Zanclus cornutus Linnaeus, 1758	S	DC

Trophic Categories: Herbivore (H); Omnivore (O); Browser of Sessile Invertebrates (BSI); Diurnal Carnivore (DC); Nocturnal Carnivore (NC); Piscivore (Pi); Diurnal Planktivore (DPL); Nocturnal Planktivore (NPL); Unknown (NA)

Discussion

This is the first assessment of ichthyofaunal diversity of the seas around Praia do Tofo and Praia da Barra in southern Mozambique. Through the use of underwater observations supplemented by past records, 353 species were recorded from the coral reefs spanning 40 km of the southern coastline of Inhambane province. These results provide a higher estimation of fish species richness than is predicted by the Coral Fish Diversity Index. The diversity of the PTPB area is similar to that recorded in other areas of the southwestern Indian Ocean where visual observations have been the primary data collection method (Table 3) (Maggs *et al.*, 2010; Chabanet & Durville, 2005; Gillibrand *et al.*, 2007; Durville *et al.*, 2003). In particular, SR_{theor} shows high similarity to areas in southern Mozambique and South Africa that are fully or partially protected (e.g. Floros *et al.*, 2012; Maggs *et al.*, 2010; Pereira *et al.*, 2004).

The sub-tropical reefs of the PTPB area have low levels of coral cover (Motta *et al.*, 2002), which may be assumed to result in a low diversity of fish communities (Komyakova *et al.*, 2013). However, the current study found a relatively high fish species richness which is comparable to areas with higher coral cover (e.g. Gillibrand *et al.*, 2007; Table 3). This may be partly explained

Table 3. The diversity of reef fish species and families from other areas in the southwestern Indian Ocean. SRobs = recorded species richness; SRtheor = theoretical species richness predicted by the Coral Fish Diversity Index (Allen & Werner, 2002).

Location	Geographical Coordinates	SR_{obs}	SR_{theor}	No. of families	SR_{obs} to no. of families ratio (2 d. p.)	Source
Praia do Tofo and Praia da Barra	23°51'S, 33°54'E	353	329	79	4.47:1	Present study
Bazaruto Archipelago National Park	21°43'S, 35°27'E	249	359	40	6.23:1	Maggs *et al.* 2010
Maputo Bay	26°S, 32°54'E	327	349	58	5.64:1	Schleyer & Pereira, 2014
Juan de Nova	17°03'S, 42°43'E	299	423	55	5.44:1	Chabanet & Durville, 2005
Andavadoaka	22°05'S, 43°12'E	334	430	58	5.76:1	Gillibrand *et al.* 2007
Glorieuses Islands	11°33'S, 47°20'E	332	451	57	5.82:1	Durville *et al.* 2003
St. Lucia Marine Reserve	27°44'S, 32°40'E	258	349	48	5.38:1	Floros *et al.* 2012
Mafia Island	7°52'S, 39°45'E	394	515	56	7.04:1	Garpe & Ohman, 2003
Europa Island	22°21'S, 40°21'E	389	468	62	6.27:1	Fricke *et al.* 2013
Ponta do Ouro Partial Marine Reserve	26°27'S, 32°56'E	376	318	90	4.18:1	Pereira *et al.* 2004

by the extensive visual sampling design used. The high sampling time employed in this study (over 36 hours of underwater observations) allowed for the observation of some cryptic species that would be missed by shorter visual surveying. For example, four species of gobies and eight species of blennies were recorded on reefs of PTPB (Table 2). Therefore, while visual censuses generally do not accurately capture the diversity of cryptobenthic species (Ackerman & Bellwood, 2000), this limitation can be reduced through extensive sampling. A high number of families were also recorded in comparison to other areas in the region (Table 3), suggesting a high proportion of uncommon species were observed. The impact of greater sampling effort on species records is evident in the results of Gillibrand *et al.* (2007). These authors examined a smaller area than the current study and recorded 334 species by conducting visual observations across a twelve month period. In contrast, Chabanet & Durville (2005) recorded more than 50 fewer species around Juan de Nova Island through 30 hours of visual surveying. This highlights that sampling effort does not solely account for the high fish diversity recorded in the PTPB area.

The present study necessarily examined a large depth range (1-32 m) in order to capture the range of habitats present in the area. As such, a higher number of specialist species are expected to have been identified due to the wider variety of physical habitats and biological conditions (Bridge *et al.*, 2016; Jankowski *et al.*, 2015). Significant changes in fish assemblages with depth have been observed in previous studies (Friedlander & Parrish, 1998) and this is likely to be the same in the current study. This may also explain the high number of families observed (Table 3).

Coastal upwelling in these seas drive high levels of primary productivity and in turn supports abundant populations of large charismatic species (Rohner *et al.*, 2014). It is also likely to influence the reef fish diversity of the area, potentially boosting species richness in two ways. Firstly, cooler waters allow the area to support

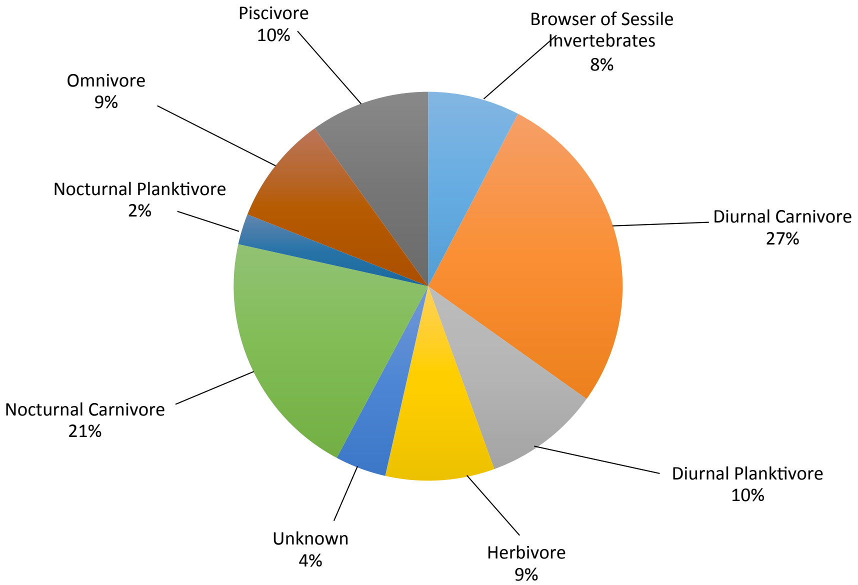

Figure 2. Trophic structure of the PTPB reef fish community estimated from past literature.

species more common in temperate waters (e.g. *Seriola lalandi*, *Oplegnathus robinsoni*). Anderson *et al.* (2015) proposed the appearance of species characteristic of higher latitudes in their sub-tropical study site to regions of cool water upwelling. In the current study water temperatures were recorded between 18-29°C; the influx of cool water may be influencing diversity in the sub-tropical PTPB area. Secondly, upwelling supports high plankton abundance which can reduce competitive exclusion in planktivorous species (Abrams, 1995). This would allow the co-existence of more species on lower trophic levels; an effect which may then propagate up the food chain to produce a higher diversity of secondary and tertiary consumers. The relationship between primary productivity and diversity has been previously acknowledged (Waide *et al.*, 1999). However, the recorded proportion of planktivores in this study is very similar to other areas of the southwestern Indian Ocean (Table 4). Therefore, the effect of high primary productivity in reducing competitive exclusion, if present, appears not to influence this trophic level.

Table 4. Trophic structure recorded from other areas of the southwestern Indian Ocean.

Location	Carnivores (incl. planktivores; % of total)	Planktivores (% of total)	Herbivores (% of total)	Omnivores (% of total)	Source
Bazaruto Archipelago National Park	76	10	12	12	Maggs *et al.*, 2010
Praia do Tofo and Praia da Barra	78	12	9	9	Present study
Juan de Nova	73	13	16	11	Chabanet & Durville, 2005
Andavadoaka	76	11	13	11	Gillibrand *et al.*, 2007
Glorieuses Islands	73	15	15	12	Durville *et al.*, 2003
Geyser and Zelee Banks	72	17	16	12	Chabanet *et al.*, 2002

Carnivores, *sensu lato*, represented the vast majority of the fish diversity in the PTPB area. The relative proportions of carnivores, omnivores and herbivores are similar to other areas in the region (Table 4), supporting the observation of Kulbicki (1988) that the trophic structure of fish communities is consistent across a region. It may suggest that these reefs are in good health (as per Harmelin-Vivien, 1979); however, caution should be exercised when using trophic structure to imply reef health in this instance due to the potentially confounding effect of high primary productivity.

This study demonstrates that the PTPB area is biologically rich beyond its resident megafauna populations, and indicates additional value to the ecotourism industry in the region. Whilst the relatively large sampling extent precludes comprehensive comparisons with other studies in the southwestern Indian Ocean, the results show that the reef ecosystems of PTPB host a fish community comparable to more isolated, or protected areas. This suggests that these reefs are in relatively good condition despite a large associated human population. The high proportion of carnivores recorded here supports this suggestion; however, local upwelling make these metrics questionable measures of reef health. Therefore, targeted research is needed to examine the current health status of these reefs and to provide a stronger baseline for monitoring impacts of future expansion of tourism and fishing activities in the area.

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References

Abrams PA (1995) Monotonic or unimodal diversity-productivity gradients: what does competition theory predict? Ecology 76: 2019-2027. doi: 10.2307/1941677

Ackerman JL, Bellwood DR (2000) Reef fish assemblages: a re-evaluation using enclosed rotenone stations. Marine Ecology Progression Series 206: 227-237

Allen GR, Werner TB (2002) Coral reef fish assessment in the 'coral triangle' of southeastern Asia. Environmental Biology of Fishes 65: 209-214. doi: 10.1023/A:1020093012502

Anderson AB, Carvalho-Filho A, Morais RA, Nunes LT, Quimbayo JP, Floeter SR (2015) Brazilian tropical fishes in their southern limit of distribution: checklist of Santa Catarina's rocky reef ichthyofauna, remarks and new records. Check List 11: art1688. doi: 10.15560/11.4.1688

Bellwood DR, Hughes TP (2001) Regional-scale assembly rules and biodiversity of coral reefs. Science, 292: 1532-1534

Bridge TCL, Luiz OJ, Coleman RR, Kane CN, Kosaki RK (2016) Ecological and morphological traits predict depth-generalist fishes on coral reefs. Proceedings of the Royal Society B 283: 20152332. doi: 10.1098/rspb.2015.2332

Chabanet P, Durville P (2005) Reef fish inventory of Juan de Nova's natural park (Western Indian Ocean). Western Indian Ocean Journal of Marine Science 4: 145-162. doi: 10.4314/wiojms.v4i2.28484

Chabanet P, Tessier E, Mulochau T (2002) Fish communities of the Geyser and Zéléé coral banks (Western Indian Ocean). Cybium 26: 11-26

Cleland EE (2011) Biodiversity and ecosystem stability. Nature Education Knowledge 3, pp 14

Durville P, Chabanet P, Quod JP (2003) Visual census of the reef fishes in the natural reserve of the Glorieuses Islands (Western Indian Ocean). Western Indian Ocean Journal of Marine Science 2: 95-104

Floros C, Schleyer M, Maggs JQ, Celliers, L (2012) Baseline assessment of high-latitude coral reef fish communities in southern Africa. African Journal of Marine Science 34: 55-69. doi: 10.2989/1814232X.2012.673284

Fricke R, Durville P, Bernardi G, Borsa P, Mou-Tham G, Chabanet P (2013) Checklist of the shore fishes of Europa Island, Mozambique Channel, southwestern Indian Ocean, including 302 new records. Stuttgarter Beiträge zur Naturkunde A, Neue Serie 6: 247-276

Friedlander AM, Parrish JD (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224: 1-30. doi: 10.1016/S0022-0981(97)00164-0

Garpe KC, Öhman MC (2003) Coral and fish distribution patterns in Mafia Island Marine Park, Tanzania: fish-habitat interactions. Hydrobiologia 498: 191-211. doi: 10.1023/A:1026217201408

Gillibrand CJ, Harries AR, Mara E (2007) Inventory and Spatial Assemblage Study of Reef Fish in the Area of Andavadoaka, South-West Madagascar (Western Indian Ocean). Western Indian Ocean Journal of Marine Science 6: 183-197. doi: 10.14314/wiojms.v6I2.48239

Harmelin-Vivien ML (1979) Ichtyofaune des récifs coralliens en France Outre-Mer. ICRI. Doc. Secrétariat d'Etat à l'Outre-Mer et Ministère de l'Aménagement du Territoire et de l'Environment. 136 pp

Hiatt WR, Strasberg DW (1960) Ecological Relationship of the Fish Fauna on Coral Reefs of the Marshall Islands. Ecological Monographs 30: 65-127

Hobson ES (1974) Feeding Relationships of Teleostean Fish on Coral Reefs in Kona, Hawaii. Fishery Bulletin 72: 915-1031

Instituto Nacional de Estatística (2007) Recenseamento Geral da População e Habitação, Indicadores Socio--Demográficos: Província da Inhambane. 3º Censo Geral da População e Habitação, pp 5

Jankowski MW, Graham NAJ, Jones GP (2015) Depth gradients in diversity, distribution and habitat specialisation in coral reef fishes: implications for the depth-refuge hypothesis. Marine Ecology Progression Series 540: 203-215. doi: 10.3354/meps11523

Komyakova V, Munday PL, Jones GP (2013) Relative Importance of Coral Cover, Habitat Complexity and Diversity in Determining the Structure of Reef Fish Communities. PLoS One 8: e83178. doi: 10.1371/journal.pone.0083178

Kulbicki M (1988) Patterns in the trophic structure of fish populations across the SW lagoon of New Caledonia. Proceedings of the 6th International Coral Reef Symposium, Townsville, Australia (August 8-12) 2: 305-312

Maggs JQ, Floros C, Pereira MAM., Schleyer MH (2010) Rapid Visual Assessment of Fish Communities on Selected Reefs in the Bazaruto Archipelago. Western Indian Ocean Journal of Marine Science 9: 115-134

Motta H, Pereira MAM, Gonçalves M, Ridgway T, Schleyer MH (2002) Coral reef monitoring in Mozambique (2000). MICOA/CORDIO/ORI/WWF. Maputo, Mozambique Coral Reef Management Programme

Mutimucuio M, Meyer D (2011) Pro-poor employment and procurement: a tourism value chain analysis of Inhambane peninsula, Mozambique. In: van der Duim R, Meyer D, Saarinen J, Zellmer K (eds) New alliances for tourism, conservation and development in Eastern and Southern Africa. Eburon, Delft

Myers RF (1999) Micronesian Reef Fishes. Coral Graphics, Barrigada, Guam. 298 pp

Pereira MAM (2000) Preliminary checklist of reef-associated fishes of Mozambique. MICOA, Maputo, pp 21

Pierce SJ, Méndez-Jiménez A, Collins K, Rosero-Caicedo M, Monadjem A (2010) Developing a Code of Conduct for whale shark interactions in Mozambique. Aquatic Conservation: Marine and Freshwater Ecosystems 20: 782-788. doi: 10.1002/aqc.1149

Rohner CA, Pierce SJ, Marshall AD, Weeks SJ, Bennett MB, Richardson AJ (2013) Trends in sightings and environmental influences on a coastal aggregation of manta rays and whale sharks. Marine Ecology Progression Series 482: 153-168. doi: 10.3354/meps10290

Rohner CA, Weeks SJ, Richardson AJ, Pierce SJ, Magno-Canto MM, Feldman GC, Cliff G, Roberts MJ (2014) Oceanographic influences on a global whale shark hotspot in southern Mozambique. PeerJ PrePrints 2: e661v1. doi: 10.7287/peerj.preprints.661v1

Schleyer MH, Celliers L (2005) The coral reefs of Bazaruto Island, Mozambique, with recommendations for their management. Western Indian Ocean Journal of Marine Science 4: 227-236. doi: 10.4314/wiojms.v4i2.28492

Tibiriçá Y, Birtles A, Valentine P, Miller DK (2011) Diving Tourism in Mozambique: An Opportunity at Risk? Marine Environments 7: 141-151. doi: 10.3727/154427 311X13195453162732

United Nations and World Heritage Convention (2014) Assessing marine world heritage from an ecosystem perspective. The Western Indian Ocean, UN, pp 71-92

Venables S, Winstanley G, Bowles L, Marshall AD (2016) A giant opportunity: the economic impact of manta rays on the Mozambican tourism industry – an incentive for increased management and protection. Tourism in Marine Environments 12: 51-68. doi: 10.3727/154427316X693225

Waide RB, Willig MR, Steiner CF, Mittelbach G, Gough L, Dodson SI, Juday GP, Parmenter R (1999) The relationship between productivity and species richness. Annual Review of Ecology and Systematics 30: 257-300

Westneat MW, Alfaro ME (2005) Phylogenetic relationships and evolutionary history of the reef fish family Labridae. Molecular Phylogenetics and Evolution 36: 370-390. doi:10.1016/j.ympev.2005.02.001

Wickel J, Jamon A, Pinault M, Durville P, Chabanet P (2014) Species composition and structure of marine fish communities of Mayotte Island (southwestern Indian Ocean). Cybium 38: 179-203. doi: 10.1016/j.biocon.2013.12.029 0006-3207

A feeding aggregation of Omura's whale, *Balaenoptera omurai*, off Nosy Be, Mozambique Channel

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Abstract

A feeding aggregation of Omura's whales, *Balaenoptera omurai*, was documented off Nosy Be Island at the northeastern entrance of the Mozambique Channel in November 1994. Underwater photographs of live individuals illustrated sub-surface skimming as the main feeding behaviour, with small crustaceans, small jellyfish and other gelatinous micronecton identified as prey. A precise description of the whales' pigmentation patterns completes previous descriptions from the recent literature.

Keywords: Omura's whale, feeding aggregation, Mozambique Channel

Introduction

The recently discovered Omura's whale, *Balaenoptera omurai* Wada, Oishi and Yamada 2003, has been reported mainly from the tropical waters of the Atlantic, Indian and western-Pacific Oceans (Fig. 1). The osteology of the skull has been described in detail from a number of specimens from the Indian and Pacific Oceans (Wada *et al*., 2003; Yamada *et al*., 2006a; 2006b; 2008). DNA markers have been used to ascertain identification in a number of captured, stranded (Sasaki *et al*., 2006; Jung *et al*., 2016; Ottewell *et al*., 2016; Ranjbar *et al*., 2016; Cypriano-Souza *et al*., 2017; Xu *et al*., 2017), as well as live Omura's whales (Kahn and Pet 2002; Cerchio *et al*., 2015). Cerchio *et al*. (2015) have reported regular sightings of Omura's whales (whose identity was validated by mitochondrial DNA sequence) along the northwestern coast of Madagascar, mainly off the Ampasindava Peninsula and also north of Nosy Be Island from 2007-2014. A series of diapositives of a previously unidentified balaenopterid whale taken off Nosy Be twenty years ago by one of us (PL), were recently resurrected. The present note is a brief account of the observations made on these whales, now identified as Omura's whales, which were part of a feeding aggregation of up to 12 individuals. Some of their external morphological features and their pigmentation patterns are described, and details are provided on their feeding behaviour, thus adding to the knowledge of the external aspect and behaviour of Omura's whale.

Methods

From July 1991 to December 1995, and again in June-August 1998 and June-August 2000 one of us (PL) undertook field work along the reef plateau west of Nosy Be island (northern Mozambique Channel), using a 5-meter outboard motorboat for daily to weekly outings at sea. No outing occurred from January to February. Rorquals of moderately large size, from approximately 8 m to approximately 12 m, were observed on almost every occasion, from June to September, every year and occasionally in October and November. Aggregations of whales, with up to a dozen individuals within a radius of less than 500 m, were sighted on 06 November 1994 at around 10h00 local time. The coordinates were 13°26'S, 48°05'E. The bottomdepth was between 40 m and 80 m, sloping gently westwards towards the shallower reef plateau. On that occasion, the boat was stopped and PL free dived amid the whale aggregation for about one hour to take underwater pictures. Three of the pictures are presented here (Fig. 2) to illustrate the whales' external morphological features, pigmentation patterns, and feeding behaviour.

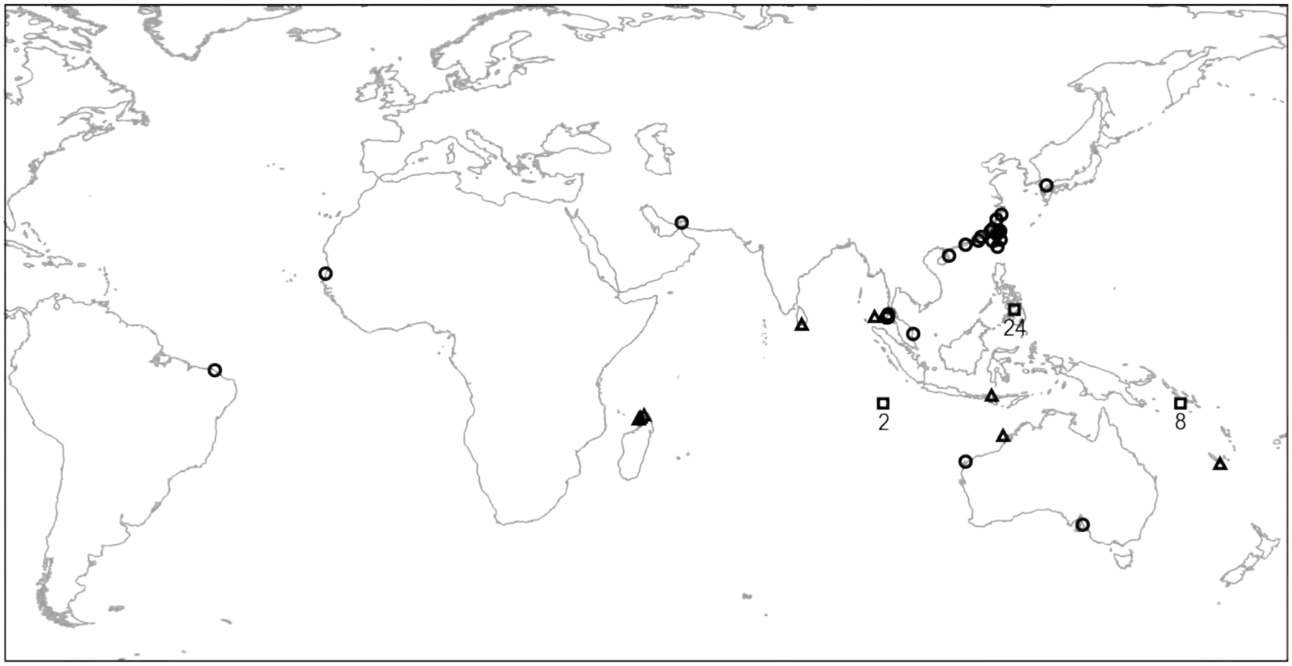

Figure. 1. Point-map distribution of Omura's whale as obtained from sightings (Kahn and Pet, 2002; Yamada, 2009; Krajewsky, 2012; Cerchio *et al.*, 2015, and references therein; de Vos, 2017; present report) symbolized by triangles; strandings (Wada *et al.*, 2003; Yamada *et al.*, 2006b; Ponnampalam, 2012; Jung *et al.*, 2016; Ottewell *et al.*, 2016; Ranjbar *et al.*, 2016; Cypriano-Souza *et al.*, 2017; Xu *et al.*, 2017, and references therein; also including three presumably stranded specimens reported from Thailand, and six from Taiwan, by Yamada *et al.* (2006a)] symbolized by circles; and captures (Wada *et al.*, 2003; Yamada *et al.*, 2008) symbolized by squares, with number of specimens reported.

Results and Discussion

Seen from above, the maxilla had a slightly pointed ogival shape (Fig. 2A). The rostrum bore a single median ridge, and two or three subtle lateral grooves were visible, parallel to the median ridge each side of it (Fig. 2A). The dorsal fin was relatively small, falcate and recurved, its tip pointing backwards (Fig. 2C). The pigmentation of the right mandible was light (Fig. 2B) while that of the left mandible was dark (Fig. 2C). Asymmetry in pigmentation was also visible on the inner part of the lip, which was dark on the right and light on the left (Fig. 2A, C). A series of three parallel, S-shaped dark chevrons connecting the eye and the posterior edge of the mouth to the nuchal region was visible on the right side (Fig. 2B), apparently not matched by symmetrical chevrons on the left side (Fig. 2B, C). A lighter-grey, Z-shaped chevron connecting the axil to the anterior part of the back below the shoulders was visible on the right side (Fig. 2B) and a symmetrical, S-shaped chevron was visible on the left side (Fig. 2B, C). The flipper's anterior edge was light-pigmented, contrasting with the darker pigmentation of the flipper's dorsal side (Fig. 2A-C).

The whales were observed feeding on a large swarm of zooplankton and micronecton that included small crustaceans, small jellyfish and other gelatinous organisms. The main mode of feeding was by skimming, with the animal gliding at shallow depth (less than 5 m below surface), mouth slightly gaping, allowing the flow of filtered seawater to escape laterally along the gaping rear extremity of the mandible (Fig. 2A, C). Lunge feeding was also observed occasionally, when the rorqual opened its mouth wide and gulped large quantities of gelatinous micronecton. On one occasion, a whale was observed defecating; the animal stood immobile in an upright position below the surface, allowing the plume of faeces to sink.

The whales documented in the present report were identified as Omura's whales on the basis of their external morphology and pigmentation, including the markedly recurved dorsal fin, the ogival shape of the rostrum, the single median ridge, and the asymmetry in pigmentation patterns (Wada *et al.*, 2003; Cerchio *et al.*, 2015; Ottewell *et al.*, 2016). Pigmentation patterns were very similar between the whales photographed by PL in 1994 (present report) and those photographed in the same area 18-20 years later (Cerchio *et al.*, 2015). In particular, two individuals presented in Figure 3 of Cerchio *et al.* (2015) exhibited a series of three parallel, dark-grey chevrons similar to that photographed in Fig. 2B. Sample monomorphism in the control-region sequences (N = 11) reported by Cerchio

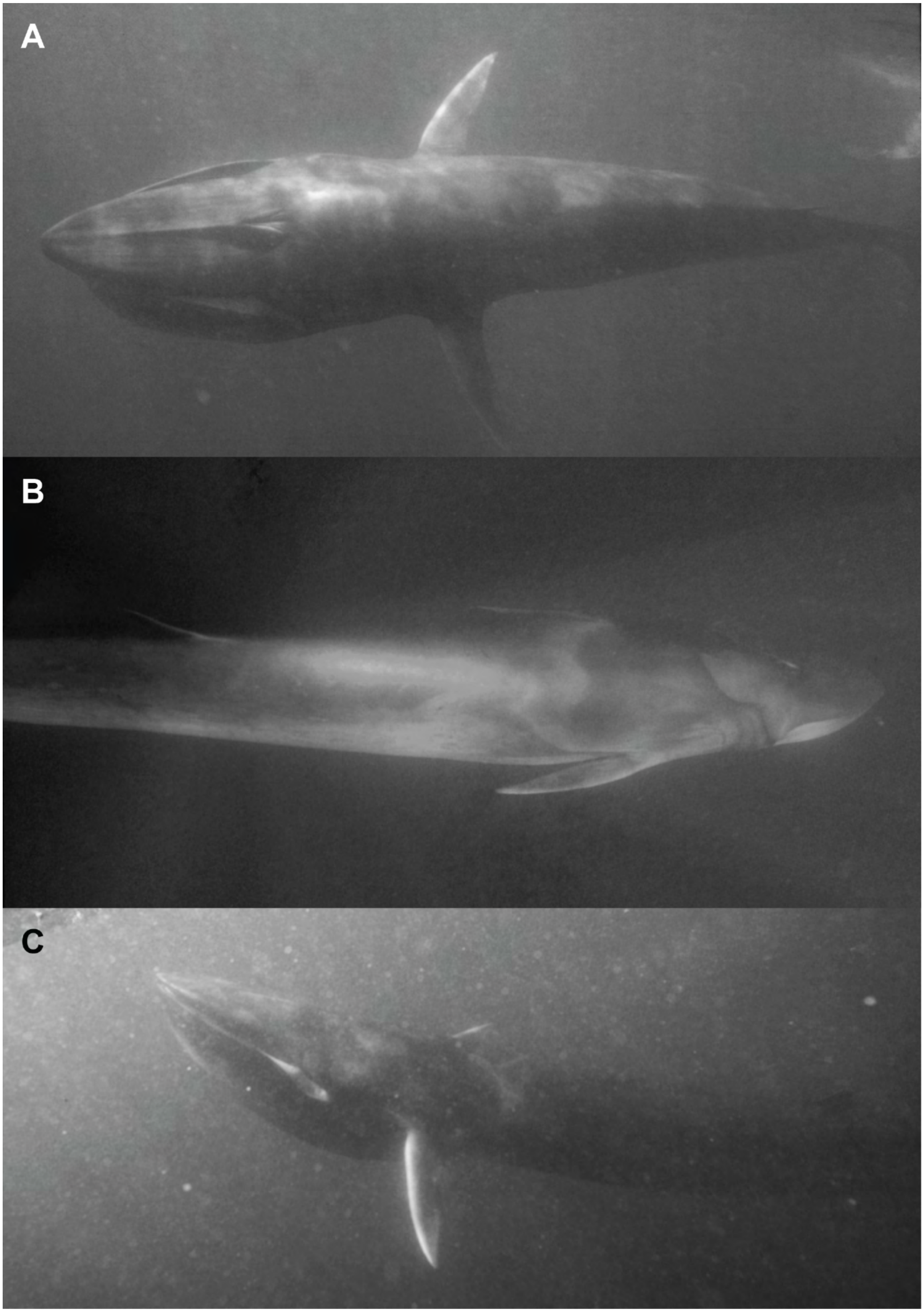

Figure 2. Omura's whales photographed off Nosy Be (13°26'S, 48°05'E), 06 November 1994. A. Skimming posture of Omura's whale, viewed from above. B. View of the right and dorsal sides of an individual. C. Backlight view of the left side of another individual, also showing a swarm of gelatinous micronecton under the surface.

et al. (2015) indicates a low genetic diversity for the population of Omura's whales off northwestern Madagascar, suggesting a low effective population size. This in turn may explain similarities in pigmentation patterns such as those observed and which at first sight appeared to differ from those of a few individuals from other areas where pigmentation patterns were partly scoreable (Western Australia: Ottewell *et al.*, 2016; Persian Gulf: Ranjbar *et al.*, 2016). However, the skin of the Western Australian specimen had likely undergone post-mortem darkening (Ottewell *et al.*, 2016) and the skin of the Persian Gulf specimen displayed cuts, scratches and abrasions on part of its surface, erasing part of the pigmentation (Ranjbar *et al.*, 2016; these injuries are ascribed to a collision with a ship). The fact that a similar three-dark chevron pattern also characterized an individual documented from off Komodo Island (Kahn and Pet, 2002) and another one from off southern Sri Lanka (de Vos, 2017) suggests that it is, at least, a pattern frequently encountered in Omura's whales from the Indian-Ocean.

The occurrence of medium-sized rorquals including Omura's whales off Nosy Be every winter and spring for five consecutive years (this report) and 20 years later again for three consecutive years (Cerchio *et al.*, 2015) may be either related to seasonal and perhaps year-round suitable trophic conditions, or to suitable conditions for reproduction, or both. Sightings of mother-calf pairs (Cerchio *et al.*, 2015), acoustic records interpreted as courtship vocalizations (Cerchio *et al.*, 2015), and the documentation of feeding behaviour (Cerchio *et al.*, 2015; present study) suggest that the continental shelf waters at the northeastern entrance of the Mozambique Channel harbour a permanent or semi-permanent breeding population of Omura's whale. The interaction of the westward-flowing extension of the South Equatorial Current with the topography of the northeastern entrance of the Mozambique Channel generates large anticyclonic eddies (Schouten *et al.*, 2003). Anticyclonic eddies provoke upwellings which in turn favour high phytoplankton production. Eddies and currents play an important part in the spatial distribution of the chlorophyll in the Mozambique Channel (Quartly and Srokosz, 2003). High chlorophyll concentrations associated with upwellings are found along the coasts of Madagascar and Mozambique, notably at the northwestern and southwestern tips of Madagascar (Zubkov and Quartly, 2003). It is possible that the particular topography of the shelf area off northwestern Madagascar favours the accumulation and retention of drifting, fast-growing zooplankton and micronecton including small jellyfish and other gelatinous animals, which Omura's whales exploit. Although poorly energetic, this diet may suffice to contribute a part of the energetic requirements of middle-sized rorquals such as Omura's whales in tropical waters, where individual energetic expenditure is less than in colder waters.

References

Cerchio S, Andrianantenaina B, Lindsay A, Rekdahl M, Andrianarivelo N, Rasoloarijao T (2015) Omura's whales (*Balaenoptera omurai*) off northwest Madagascar: ecology, behaviour and conservation needs. Royal Society Open Science 2: 150301

Cypriano-Souza AL; Oliveira de Meirelles AC; Carvalho VL; Bonatto SL (2017) Rare or cryptic? The first report of an Omura's whale (*Balaenoptera omurai*) in the South Atlantic Ocean. Marine Mammal Science 33: 80-95

de Vos A (2017) First record of Omura's whale, *Balaenoptera omurai*, in Sri Lankan waters. Marine Biodiversity Records 10: 18

Jung J-L, Mullié WC, Van Waerebeek K, Wagne MM, Ould Bilal AS, Ould Sidaty ZA, Toomey L, Méheust E, Marret F (2016) Omura's whale off West Africa: autochtonous population or inter-oceanic vagrant in the Atlantic Ocean? Marine Biology Research 12: 66-75

Kahn B, Pet J (2002) Rare whale species identified in Komodo National Park, Indonesia. Apex Environmental, Denpasar. 3 pp

Krajewsky H (2012) Extraordinarily rare whale sighting – Omura's whale (*Balaenoptera omurai*). Marine Education and Research Society, Alert Bay. https://mersociety.wordpress.com/author/mersociety/

Ottewell K, Coughran D, Gall M, Irvine L, Byrne M (2016) A recent stranding of Omura's whale (*Balaenoptera omurai*) in Western Australia. Aquatic Mammals 42: 193-197

Ponnampalam LS (2012) Opportunistic observations on the distribution of cetaceans in the Malaysian South China, Sulu and Sulawesi Seas and an updated checklist of marine mammals in Malaysia. Raffles Bulletin of Zoology 60: 221-231

Quartly GD, Srokosz MA (2003) Eddies in the southern Mozambique Channel. Deep-Sea Research Part II, Topical Studies in Oceanography 51: 69-83

Ranjbar S, Dakhteh MS, Van Waerebeek K (2016) Omura's whale (*Balaenoptera omurai*) stranding on Qeshm Island, Iran: further evidence for a wide (sub) tropical distribution, including the Persian Gulf. Journal of Marine Biology and Oceanography 5: 1-9

Sasaki T, Nikaido M, Wada S, Yamada TK, Cao Y, Hasegawa M, Okada N (2006) *Balaenoptera omurai* is a newly discovered baleen whale that represents an ancient evolutionary lineage. Molecular Phylogenetics and Evolution 41: 40-52

Schouten MW, de Ruijter WPM, van Leeuwen PJ, Ridderinkhof H (2003) Eddies and variability in the Mozambique Channel. Deep-Sea Research Part II, Topical Studies in Oceanography 50: 1987-2003

Wada S, Oishi M, Yamada TK (2003) A newly discovered species of living baleen whale. Nature 426: 278-281

Xu M, Wang X, Miao X, Wu F, Ma M, Tao C, Zhu Q (2017) Stranding Record of Omura's Whale (*Balaenoptera omurai* Wada, Oishi, and Yamada, 2003) in the Taiwan Strait, China. Aquatic Mammals 43: 289-298

Yamada T (2009) Omura's whale, *Balaenoptera omurai*. In : Ohdachi SD, Ishibashi Y, Iwasa MA, Saitoh T (eds) The wild mammals of Japan. Mammalogical Society of Japan, Kyoto. pp 330-331

Yamada TK, Chou L-S, Chantrapornsyl S, Adulyanukosol K, Chakravarti SK, Oishi M, Wada S, Yao C-J, Kakuda T, Tajima Y, Arai K, Umetani A, Kurihara N (2006a) Middle-sized balaenopterid whale specimens (Cetacea: Balaenopteridae) preserved at several institutions in Taiwan, Thailand, and India. Memoirs of the National Science Museum, Tokyo 44: 1-10

Yamada TK, Kemper C, Tajima Y, Umetani A, Janetzki H, Pemberton D (2006b) Marine mammal collections in Australia. National Science Museum Monographs 34: 117-126

Yamada TK, Kakuda T, Tajima Y (2008) Middle sized balaenopterid whale specimens in the Philippines and Indonesia. Memoirs of the National Museum of Natural Sciences, Tokyo 45: 75-83

Zubkov M, Quartly GD (2003) Ultraplankton distribution in surface waters of the Mozambique Channel – flow cytometry and satellite imagery. Aquatic Microbial Ecology 33: 155-161

Hand-held Sediment Corer for Use in Shallow, Turbulent Coastal Environments

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Abstract

A simple, cheaply-constructed corer is described for operation by SCUBA divers on marine sediments at shallow depths. It proved effective in the collection of bioclastic, reef-associated sediments to a depth of 1 m, retaining their integrity for palaeoclimatological research.

Keywords: diver-operated coring device, palaeoclimatology, sedimentation

Introduction

Palaeoclimatic reconstructions, derived from the analysis of sediment, coral or ice cores, provide a means to extract information beyond modern instrumental records (Bradley, 2014). They also provide a means to determine the response of organisms to past environmental changes (Bradley, 2014). Marine sediment cores are conventionally collected using heavy machinery and research vessels employing a variety of equipment such as vibra-, gravity-, piston-, box- or multi-corers (Schwartz, 2005). Their application is not always feasible due to financial limitations or sampling location, e.g. shallow intertidal regions, coastal areas or coral reefs that are inaccessible to large research vessels. We therefore developed an alternative coring method, a hand-held hammer corer, which can be cheaply manufactured and operated by SCUBA divers in shallow (<30 m) environments. The aim was to manufacture an economical, easy to use corer for the collection of ±1 m long cores in diver-accessible environments.

Corer design

The corer weighs ~35 kg and relies on a percussive hammer for its action, which slides along a fixed barrel (Fig. 1). It is constructed of stainless steel and has handles on top of the barrel to steady it. A hole in the barrel is used to secure core cylinders to the corer, with a pin that also serves as a stop for the sliding hammer when it is lifted. The corer can be used to drive 75 mm diameter, 1.75 m long, stainless steel core barrels into the sediment. A brass shim-stock core-catcher is riveted to the bottom of the core cylinder to minimize sediment loss (Fig. 2). This is pliable, with teeth bent inwards to retain and maintain the integrity of the sediment core. A stainless steel collar with a scampered edge is used to secure the core-catcher flush against the cylinder edge. The corer was designed for use by either one or two divers.

Trial cores

Trial cores were collected using the corer on the inshore edge of Two-mile Reef (TMR), Sodwana Bay, South Africa (Fig. 3). This shallow reef environment is known for its turbulence (Schleyer, 2000). Three cores were collected at the outer fringe of a bioclastic sediment field, on the inshore side of TMR (Fig. 3) in water depths ranging from 15.2 – 16.3 m.

Three cores (X, Y & Z) were collected by divers as depicted in Fig. 4. Upon reaching maximum penetration, the core cylinders were marked at the sediment surface, extracted, capped on both ends, and lifted to the surface using air-lift bags. It took 40 minutes on average to drive each core. Upon splitting, all three cores were intact, displayed banding and all manifested varying degrees of compaction but no disturbance (Fig. 5). Radiocarbon dating of the longest core (X)

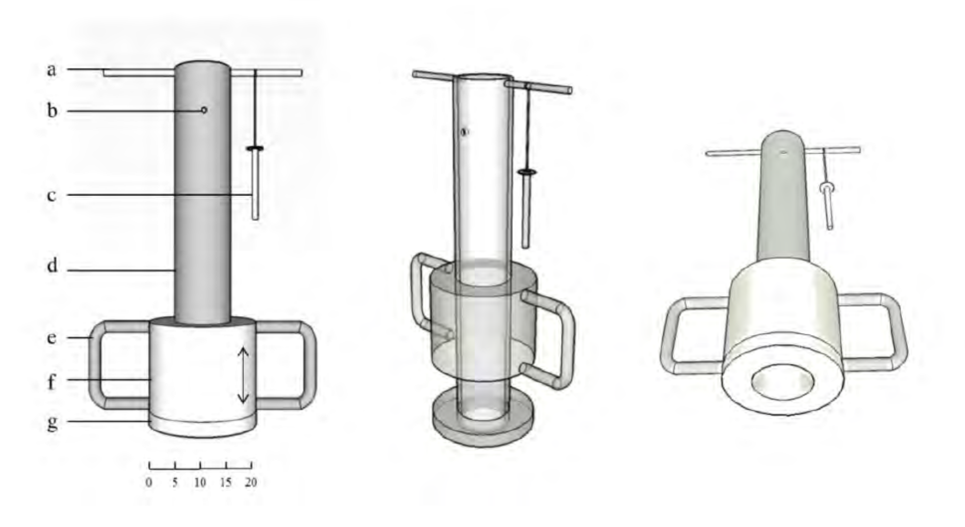

Figure 1. Scaled diagram of the hammer corer: a) top handle, b) hole in sleeve for core barrel securing pin, c) securing pin, d) stainless steel barrel which acts as the hammer slide, e) hammer handle, f) sliding hammer, and g) impact flange.

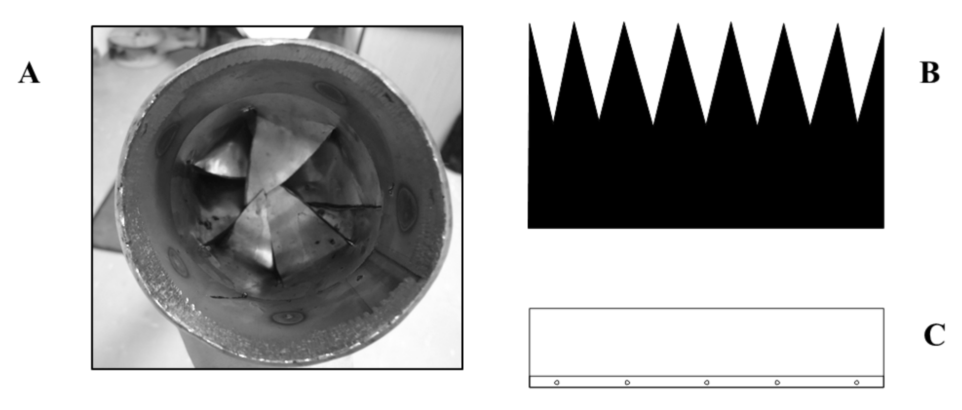

Figure 2. a) Core-catcher inside stainless steel core barrel, b) core-catcher prior to bending and c) scampered stainless steel collar used to secure core-catcher.

provided a Late Holocene starting calendar age of AD 680-920 (BP 1270-1030).

Conclusion

Overall, the hand-held hammer corer was successfully used to collect bioclastic sediment cores from a shallow, turbulent, reef-associated environment. The corer was easy to operate by one or two divers, and cores were retrieved in a short period of time. The handmade core-catcher closed upon retrieval of the cores and prevented sediment loss. The cores were intact and displayed common banding (Fig. 5). Their integrity was thus maintained, with limited disturbance during collection. A problem was encountered where coral rubble was present and this hindered the collection of cores in scattered reef habitat. The corer nevertheless provided an economical means to gather sediment cores from a shallow, turbulent reef environment and these could be used for palaeo-climatological analysis.

Acknowledgements

We are grateful to Mr Mike Gower who generously constructed the corer at nominal cost. The South African Association for Marine Biological Research (SAAMBR) and the Applied Centre for Climate and Earth Systems Science (ACCESS) provided support for the research, and our colleagues willingly assisted with core collection in the field.

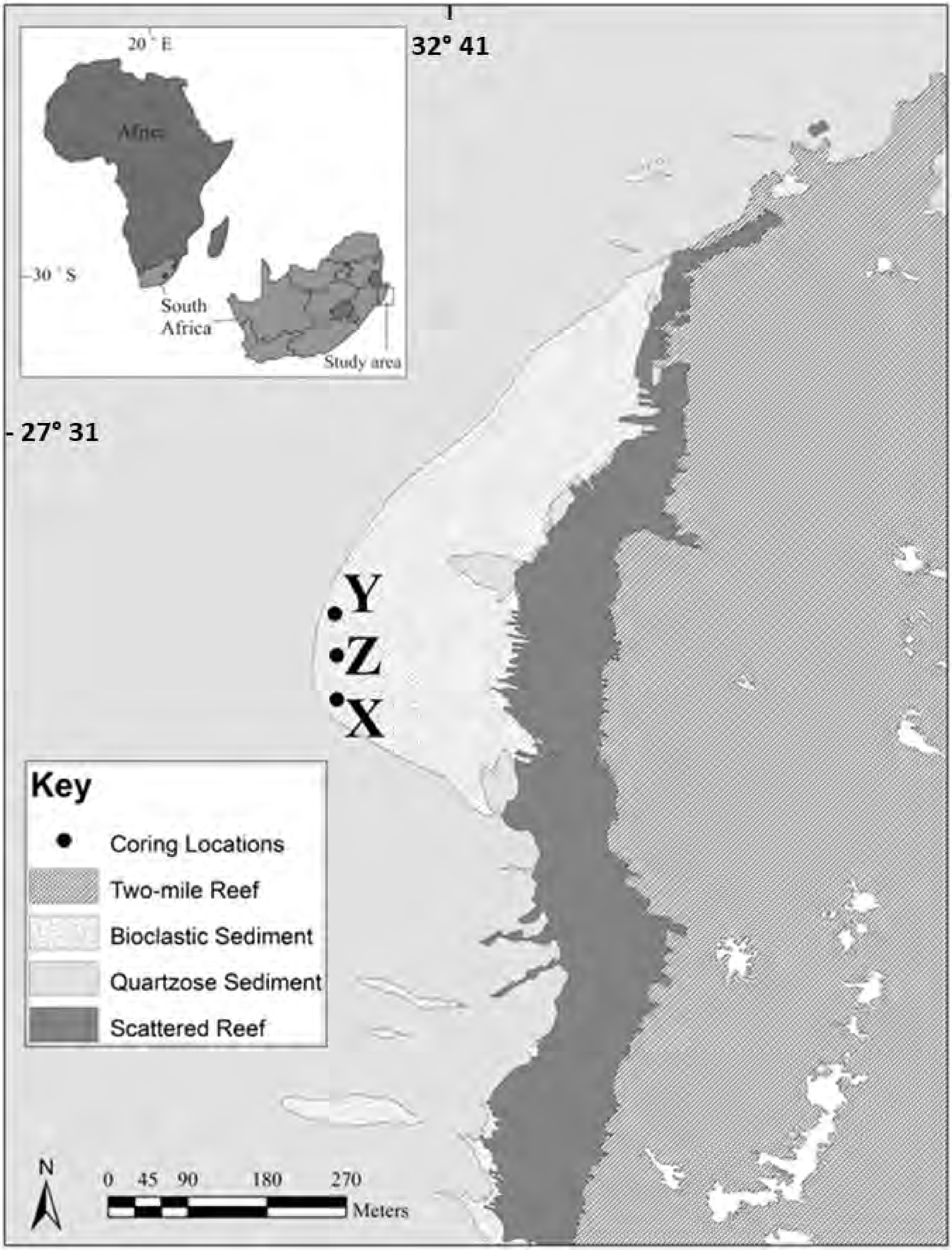

Figure 3. Map showing coring locations on the inshore edge of Two-mile Reef, Sodwana Bay, South Africa.

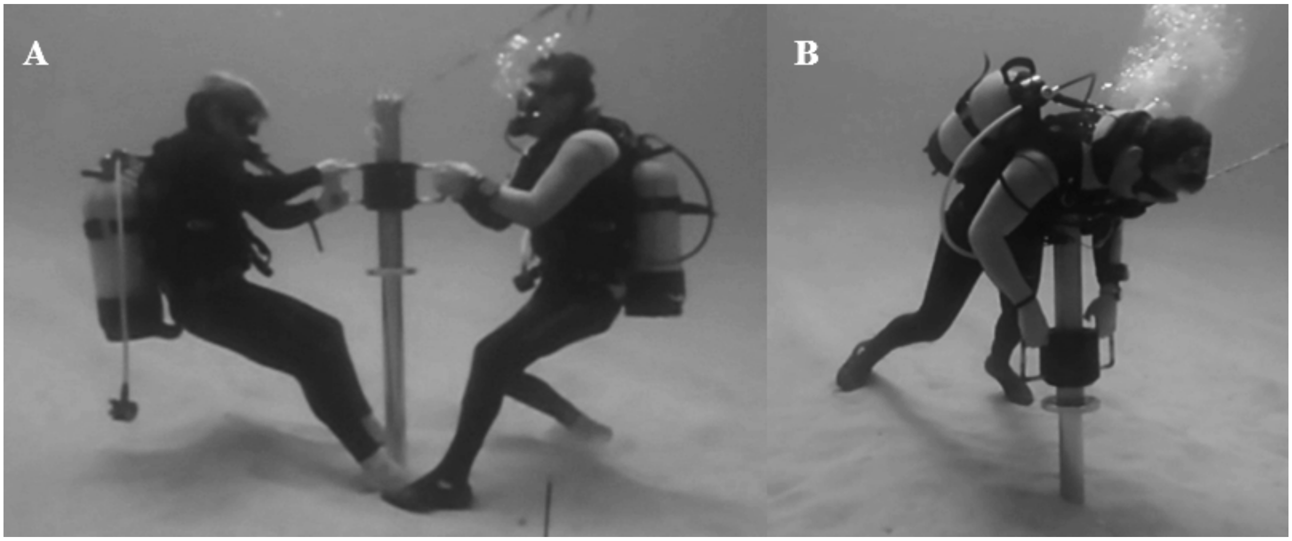

Figure 4. Corer being operated by a) a pair of divers, and b) a single diver.

Figure 5. Sediment cores (X, Y and Z) collected inshore of Two-mile Reef. Bands common to all three cores are evident. The cores were 61, 49 and 47 cm in length, respectively; the scale bars are graduated in cm.

References

Bradley R (2014) Paleoclimatology: Reconstructing Climates of the Quaternary. UK: Academic Press, Elsevier, 696 pp

Schleyer MH (2000) South African coral communities. In: McClanahan T, Sheppard C, Obura D (eds) Coral reefs of the Indian Ocean: Their ecology and conservation. Oxford University Press, New York, pp 83-105

Schwartz M (2005) Encyclopedia of Coastal Science. Springer, Netherlands, 1086 pp

Seasonal variation in the length-weight relationship and condition factor of thirty fish species from the Shimoni artisanal fishery, Kenya

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Abstract

Seasonal variation in the length-weight relationship (LWR) and condition factor were assessed for 3 704 fish specimens constituting 30 fish species belonging to 11 families. The fish were sampled from artisanal fisher catches on the south coast of Kenya between March 2014 and March 2015. The regression results for the LWR were 0.57 for *Siganus luridus* and 0.97 for *Lutjanus argentimaculatus* during the northeast monsoon (NEM), and 0.76 for *Scolopsis ghanam* and 0.98 for *Parupeneus macronema* during the southeast monsoon (SEM). The '*b*' values ranged from 1.8 for *Siganus luridus* to 4.3 for *Plectorhinchus gaterinus* during the NEM, and 1.4 for *Plectorhinchus chubbi* to 3.2 for *Parupeneus heptacanthus* during the SEM. The mean '*b*' values for the SEM and NEM seasons were 2.73 and 2.63 respectively and significantly differed from 3 (*t*–test, $P < 0.5$). Mean condition factors of 0.37 (S.E = 0.01) during the NEM, 0.34 (S.E = 0.01) during the SEM for *Hemiramphus far* and 0.56 (S.E = 0.03) during the NEM, and 0.59 (S.E = 0.03) during SEM for *Cheilio inermis* were recorded indicating that these species were feeding poorly, the environment was not conducive, or that high competition for food from other species existed, while the other species had mean condition factors above 1 during the two seasons. The condition factor significantly differed for eleven species during the two seasons ($P < 0.05$).

Keywords: Length–weight, fish species, season

Introduction

Collection of length and weight data from fishery landings is often a routine aspect in fisheries assessments which, when presented as length–weight relationships (LWR), can provide important information that is useful in the determination of biomass, population dynamics and the condition of fished populations (e.g. Duarte *et al.*, 1999; Sparre and Venema, 1998; Haimovici and Velasco, 2000).

LWR information can also be used to assess the physiological wellbeing or condition of a fish, as the heavier a fish is at a given length, the better its physiological condition. Such information can also be used as an indicator of the status of an ecosystem in which fish live. Seasonal variations in LWR and condition factor can provide information on when the marine environment is most optimal for the growth and development of fish. In Kenya, LWR studies have been documented for a number of marine species (i.e. Mbaru *et al.*, 2010; Aura *et al.*, 2011) but there are no studies that have been conducted to assess effects of seasonality on body condition. This assessment was therefore conducted to contribute to filling these information gaps.

Materials and methods

Study area

This study was conducted at Shimoni (south coast Kenya) which is located between 04°39'0"S and 39°23'0"E, adjacent to the Kisite Marine National Park and Mpunguti Marine National Reserve as indicated in Fig. 1. Generally the Kenyan coast is influenced by the movement of the inter–tropical Convergence Zone (ITCZ) creating two distinct seasons; the northeast monsoon (NEM) locally known as 'Kazi kazi', and the southeast monsoon (SEM), locally known as 'Kusi'(McClanahan, 1988). The NEM season prevails from May to September and is characterized by calm and hot weather with wave heights dropping during this time, and the SEM season prevails from November to March and is characterized by windy and cold weather accompanied by rough seas.

Data collection and analysis

Fish samples were obtained from artisanal fisher catches between March 2014 and March 2015. The catches were sorted and identified using identification guides (Lieske and Myers, 2001; Anam and Mostarda, 2012). Total length (TL) of each fish was measured from the snout to the caudal fin nearest to 0.1 cm using a standard fish length measuring board, then weighed to the nearest 0.01g (total weight) using a hand held portable electronic weighing balance.

LWR is expressed by the equation $W = a\,L^b$ where W and L represent weight and length of fish, 'a' is the initial growth index and 'b' is the equilibrium constant which measures the growth pattern of the fish. The 'b' value remains constant at 3 for ideal fish growth (Wootton, 1990) lesser or greater values indicate either positive allometric growth ($b > 3$) or negative allometric growth ($b < 3$) (Ricker, 1975). LWR of 30 species which had sufficient samples (five individuals or more) were determined by linearly regressing the log-transformed data in scatter plots to obtain the 'a' and 'b' values following the procedure described by Le Cren (1951) as:

$$\text{Log } W = \log a + b \log L$$

Where, W= weight of the fish (g), L is the observed total length (cm), 'a' is the regression intercept and 'b' is the regression slope. Condition factor was calculated using Fulton's Condition Factor (K) (Fulton, 1902) which assumes isometric growth (b = 3) indicating that the shape of the fish does not change with growth, calculated as:

$$\mathrm{K} = \frac{W \times 10^5}{\mathrm{L}^3}$$

Where, W=weight of fish (g), L=Length of fish (cm).

The relationship between length and weight was evaluated using multiple regression analysis, and the student's t–test was used to confirm whether the LWR was significantly different from 3 and whether the LWR differed between seasons ($\alpha = 0.05$). Analysis of variance (ANOVA) was then used to determine if there was a significant difference in the mean condition factor of the fish between seasons ($P < 0.05$). All statistical analysis was done using Microsoft Excel® and STATISTICA software packages.

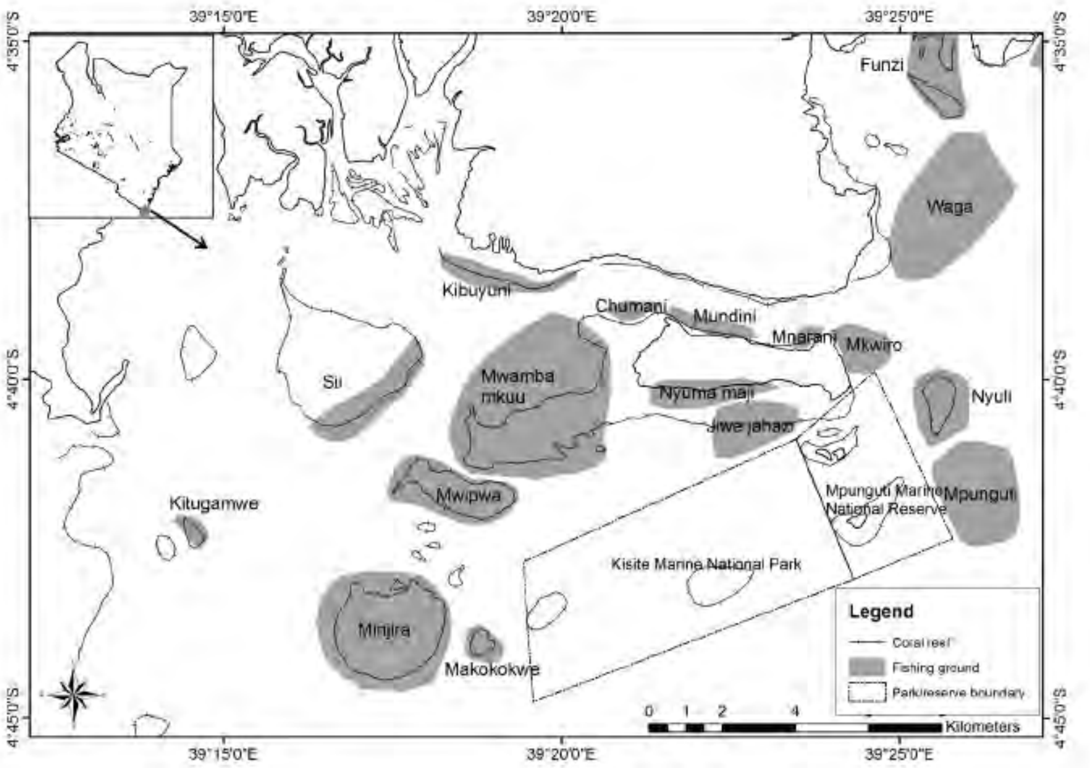

Figure 1. Location of the fishing grounds at Shimoni on the on the south coast of Kenya.

Results

A total of 3 704 fish specimens of 30 species belonging to 11 families were measured, with 2 027 fish sampled during the NEM and 1 677 fish sampled during the SEM, respectively. During the NEM the catch was dominated by the shoemaker spinefoot, *Siganus sutor* (Valenciennes, 1835) accounting for 18.0% (367) of the total catch, and snubnose emperor, *Lethrinus borbonicus* (Valenciennes, 1830) accounting for 12.7% (257) of the total catch. During the SEM the pink ear emperor, *Lethrinus lentjan* (Lacèpede, 1802) and Dory snapper, *Lutjanus fulviflamma* (Forsskål, 1775) dominated the catch accounting for 12.0% (200) and 9.6% (161), respectively (Fig. 2a and 2b).

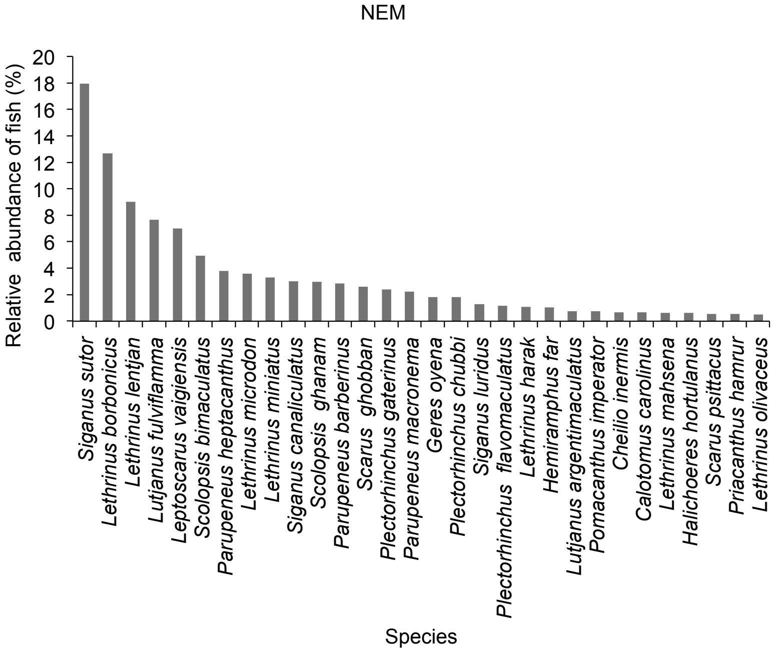

Figure 2(a). Sample size of the species analysed for the NEM season.

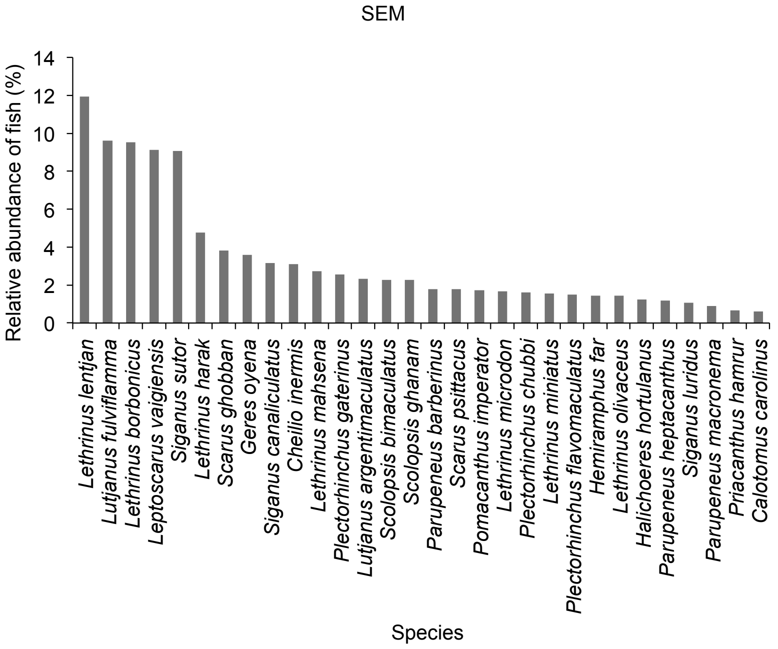

Figure 2(b). Sample size of the species analysed for the SEM season.

Length–weight relationship

A summary of the LWR for the 30 fish species is shown in Table 1a and 1b for both the NEM and SEM seasons, respectively. LWR were highly significant for all 30 species assessed with the coefficient of determination, *r*, ranging between 0.57 for dusky spinefoot, *Siganus luridus* (Rüppell, 1829) and 0.97 for mangrove jack, *Lutjanus argentimaculatus* (Forsskål, 1775) during the NEM season (Table 1a), and 0.76 for Arabian monocle bream, *Scolopsis ghanam* (Forsskål, 1775) and 0.98 for long-barbel goatfish, *Parupeneus macronema* (Lacèpede, 1801) during the SEM season (Table 1b). The '*b*' values ranged from 1.8 for *S. luridus* to 4.3 for black-spotted rubberlip, *Plectorhinchus gaterinus* (Forsskål, 1775) during the NEM and 1.4 for dusky rubberlip, *Plectorhinchus chubii* (Regan, 1919) to 3.2 for cinnabar goatfish, *Parupeneus heptacanthus* (Lacèpede, 1802) during the SEM. During the NEM a mean '*b*' value of 2.66 was recorded. During this season the thumbprint emperor, *Lethrinus harak* (Forssåkal, 1975), longface emperor, *Lethrinus olivaceus* (Valencienes, 1830), blackbarred halfbeak, *Hemiramphus far* (Forsåkal, 1775) and emperor angelfish, *Pomacanthus imperator* (Bloch, 1787) had isometric growth (b = 3), while cigar wrasse, *Cheilio inermis*, common silver-biddy, *Geres oyena*, blackspotted rubberlip, *Plectorinchus gaterinus* (Forsskål, 1775), checkerboard wrasse, *Halichoeres hortulanus* (Lacèpede, 1801) had positive allometry (b > 3), and the rest of the

Table 1 (a). Number of specimens (N), Total length (Mean ± S.E and range), Length-weight relationship (LWR), regression and growth parameters of the fish species sampled during the NEM (A-, A+ and I represent negative, positive and isometric growth, respectively)

Species		Total weight (kg)		Total length (cm)		LWR parameters			
	N	Mean ± S.E	Range	Mean ± S.E	Range	a(x10^{-5})	Slope 'b'	R	Growth
Siganus sutor	364	0.23 ± 0.01	0.02 - 0.86	26.0 ± 0.3	12.9 - 44.0	2.5	2.8	0.93	*A-*
Lethrinus borbonicus	257	0.10 ± 0.00	0.01 - 0.36	17.5 ± 0.2	10.6 - 27.7	3.4	2.7	0.91	*A-*
Lethrinus lentjan	183	0.19 ± 0.01	0.03 - 0.74	22.5 ± 0.4	10.6 - 40.0	3.6	2.7	0.94	*A-*
Lutjanus fulviflamma	155	0.11 ± 0.00	0.01 - 0.23	19.3 ± 0.2	15.0 - 28.7	21.6	2.1	0.71	*A-*
Leptoscarus vaigiensis	142	0.21 ± 0.01	0.08 - 0.51	23.1 ± 0.3	16.2 - 38.0	12.9	2.3	0.83	*A-*
Scolopsis bimaculatus	100	0.11 ± 0.00	0.03 - 0.26	18.6 ± 0.3	13.1 - 26.0	10.4	2.3	0.83	*A-*
Parupeneus heptacanthus	77	0.19 ± 0.02	0.06 - 0.75	22.8 ± 0.6	14.0 - 38.5	2.6	2.8	0.96	*A-*
Lethrinus microdon	73	0.17 ± 0.03	0.02 - 1.13	21.2 ± 1.0	12.2 - 50.2	3.8	2.6	0.95	*A-*
Lethrinus miniatus	67	0.49 ± 0.05	0.05 - 1.93	29.8 ± 1.2	13.9 - 49.7	5.4	2.6	0.83	*A-*
Siganus canaliculatus	61	0.18 ± 0.01	0.07 - 0.45	23.7 ± 0.5	16.8 - 33.6	6.5	2.5	0.93	*A-*
Scolopsis ghanam	60	0.08 ± 0.00	0.03 - 0.14	16.8 ± 0.2	12.5 - 22.6	2.2	2.9	0.88	*A-*
Parupeneus barberinus	58	0.13 ± 0.02	0.03 - 0.53	20.4 ± 0.8	11.8 - 36.9	3.5	2.7	0.95	*A-*
Scarus ghobban	53	0.48 ± 0.09	0.07 - 3.65	28.4 ± 1.2	15.5 - 64.6	6.3	2.6	0.92	*A-*
Plectorhinchus gaterinus	49	0.31 ± 0.02	0.05 - 0.60	21.7 ± 0.3	16.0 - 26.5	0.0	4.3	0.66	*A+*
Parupeneus macronema	45	0.08 ± 0.01	0.04 - 0.26	17.4 ± 0.7	13.0 - 27.5	4.6	2.6	0.88	*A-*
Plectorhinchus chubbi	37	0.07 ± 0.15	0.03 - 4.10	33.4 ± 2.4	13.5 - 73.9	2.8	2.8	0.94	*A-*
Geres oyena	37	0.20 ± 0.01	0.09 - 0.35	24.0 ± 0.5	18.3 - 29.5	0.6	3.3	0.88	*A+*
Siganus luridus	26	0.08 ± 0.00	0.04 - 0.13	17.7 ± 0.3	15.0 - 20.8	40.5	1.8	0.57	*A-*
Plectorhinchus flavomaculatus	24	0.36 ± 0.09	0.08 - 1.72	25.3 ± 2.0	15.8 - 50.0	5.6	2.6	0.95	*A-*
Lethrinus harak	22	0.28 ± 0.03	0.12 - 0.72	27.0 ± 0.7	23.2 - 36.8	1.2	3.0	0.96	*I*
Hemiramphus far	21	0.18 ± 0.01	0.09 - 0.27	36.3 ± 0.8	27.9 - 42.2	0.4	3.0	0.95	*I*
Lehtrinus mahsena	13	0.52 ± 0.12	0.17 - 1.82	29.3 ± 2.1	21.7 - 48.2	3.9	2.7	0.96	*A-*
Lutjanus argentimaculatus	15	0.54 ± 0.21	0.17 - 3.33	29.6 ± 3.0	21.0 - 65.0	3.6	2.7	0.97	*A-*
Pomacanthus imperator	15	1.23 ± 0.14	0.08 - 1.83	32.8 ± 1.8	15.5 - 38.8	1.7	3.0	0.96	*I*
Scarus rubroviolaceus	15	0.49 ± 0.14	0.11 - 1.86	28.3 ± 2.7	17.8 - 51.1	9.2	2.5	0.95	*A-*
Cheilio inermis	14	0.16 ± 0.03	0.04 - 0.43	29.1 ± 1.5	20.8 - 40.5	0.2	3.3	0.95	*A+*
Calotomus carolinus	14	0.31 ± 0.04	0.16 - 0.69	25.0 ± 1.1	19.6 - 33.7	5.3	2.7	0.96	*A-*
Lethrinus olivaceus	10	0.50 ± 0.08	0.13 - 0.96	34.0 ± 2.3	21.7 - 43.0	3.0	2.7	0.93	*I*
Priacanthus harmrur	11	0.27 ± 0.03	0.14 - 0.43	27.1 ± 1.5	21.0 - 34.0	37.2	2.0	0.76	*A-*
Halichoeres hortulanus	13	0.14 ± 0.01	0.07 - 0.22	21.0 ± 0.5	17.9 - 24.0	0.4	3.4	0.88	*A+*

species had negative allometry (b < 3). During the SEM *L. fulviflamma* and *S. luridus* had a mean 'b' value of 3.0 indicating isometric growth while *P. heptacanthus* had a 'b' value of 3.2 indicating positive allometry, and the rest of the species had negative allometry. The mean 'b' value of the fish species was low for the two seasons as most had negative allometry, hence did not obey the cubic law (Wootton, 1990). Student's t–test indicated that the mean 'b' values for NEM (b = 1.4–3.2; mean = 2.63; SD = 0.332) and SEM (b = 1.8–4.3; mean = 2.73; SD = 0.469) differed significantly from 3 (t = – 5.809, P = 0.000: NEM; and t = – 3.187, P = 0.003: SEM) indicating that the cubic law does not apply to most of the fish species in this analysis.

Condition factor (K)

The results indicate that the condition factor for all fish species was above 1 except for *H. far* and *C. inermis* which had condition factors of less than 1 during the two seasons. *H. far* had the lowest condition factor of 0.34, S.E = 0.01 during the SEM and 0.37, S.E = 0.01 during the NEM, while *P. imperator* had the highest condition factor of 3.14, S.E = 0.12 during the SEM, and 3.11, S.E = 0.05 during the NEM. However, there was a significant difference between the weights of the fish sampled during the NEM and SEM, and the mean condition factor of eleven fish species differed significantly between the two seasons (P < 0.05) (Table 2).

Table 1 (b). Number of specimens (N), Total length (Mean ± S.E and range), Length-weight relationship (LWR), regression and growth parameters of the fish species sampled during the SEM (A-, A+ and I represent negative, positive and isometric growth, respectively).

Species		Total weight (kg)		Total length (cm)		LWR parameters			
	(N)	Mean ± S.E	Range	Mean ± S.E	Range	a(x 10^{-5})	slope 'b'	R	Growth
Siganus sutor	152	0.16 ± 0.11	0.04-0.52	21.8 ± 12.20	12.2 - 35.9	4.2	2.6	0.96	*A-*
Lethrinus borbonicus	160	0.08 ± 0.04	0.02-0.24	15.8 ± 0.22	10.1 - 25	8.7	2.4	0.88	*A-*
Lethrinus lentjan	200	0.15 ± 0.13	0.03-0.64	20 ± 0.41	11 - 34.2	3.4	2.7	0.95	*A-*
Lutjanus fulviflamma	161	0.11 ± 0.04	0.02-0.30	18.6 ± 0.18	12.5 - 27.5	1.7	3.0	0.70	*I*
Leptoscarus vaigiensis	153	0.22 ± 0.09	0.07-0.54	22.8 ± 0.26	16.6 - 31.8	6.6	2.6	0.90	*A-*
Scolopsis bimaculatus	38	0.13 ± 0.03	0.07-0.23	20.6 ± 0.38	16.5 -26	3.6	2.7	0.95	*A-*
parupeneus heptacanthus	20	0.17 ± 0.07	0.04-0.28	22.7 ± 0.71	16.2 - 27	0.7	3.2	0.95	*A+*
Lethrinus microdon	28	0.23 ± 0.19	0.04-0.80	25.5 ± 1.45	14.4 - 42.9	4.8	2.6	0.95	*A-*
Lethrinus miniatus	26	0.08 ± 0.05	0.03 - 0.26	16.1 ± 0.57	11.4 - 25.6	5.5	2.6	0.90	*A-*
Siganus canaliculatus	53	0.21 ± 0.14	0.03 - 0.48	23.7 ± 0.82	11.9 - 33.5	1.9	2.9	0.97	*A-*
Scolopsis ghanam	38	0.08 ± 0.02	0.04 - 0.13	16.8 ± 0.28	12.0 - 21.0	22.8	2.1	0.76	*A-*
Parupeneus barberinus	30	0.12 ± 0.09	0.03 - 0.40	19.6 ± 0.84	13.3 - 32.4	5.5	2.5	0.92	*A-*
Scarus ghobban	64	0.28 ± 0.33	0.08 - 2.55	23.8 ± 0.76	16.0 - 53.9	2.4	2.9	0.92	*A-*
Plectorhinchus gaterinus	43	0.21 ± 0.13	0.05 - 0.65	22.5 ± 0.70	13.4 - 38.2	2.6	2.9	0.96	*A-*
Parupeneus macronema	15	0.13 ± 0.12	0.03 - 0.47	20.1 ± 1.51	13.0 - 35.2	1.9	2.9	0.98	*A-*
Geres oyena	60	0.04 ± 0.02	0.02 - 0.10	11.7 ± 0.44	8.8 - 20.0	137.0	1.4	0.88	*A-*
Plectorhinchus chubbi	27	0.45 ± 0.64	0.04 - 3.22	28.7 ± 1.92	16.8 - 60.9	4.7	2.6	0.90	*A-*
Siganus luridus	18	0.07 ± 0.02	0.04 - 0.14	16.5 ± 0.38	14.3 - 20.0	1.5	3.0	0.88	*I*
Plectorhinchus flavomaculatus	25	0.34 ± 0.25	0.13 - 1.01	26.7 ± 1.22	18.1 - 40.4	7.2	2.5	0.94	*A-*
Lethrinus harak	80	0.23 ± 0.13	0.05 - 0.72	23.9 ± 0.54	13.7 - 36.0	3.5	2.7	0.93	*A-*
Hemiramphus far	24	0.21 ± 0.06	0.09 - 0.35	39.1 ± 0.81	28.0 - 49.5	0.9	2.7	0.89	*A-*
Lutjanus gibbus	5	0.23 ± 0.22	0.08 - 0.62	23.6 ± 3.04	17.5 - 35.1	1.8	2.9	0.98	*A-*
Lutjanus argentimaculatus	39	0.65 ± 0.71	0.12 - 3.30	33.8 ± 1.64	19.6 - 64.6	4.7	2.6	0.95	*A-*
Pomacanthus imperator	29	1.40 ± 0.36	0.58 - 2.10	35.4 ± 0.64	26.0 - 39.6	10.7	2.7	0.93	*A-*
Scarus rubroviolaceus	6	0.21 ± 0.20	0.10 - 0.62	21.8 ± 2.63	17.9 - 34.8	4.6	2.7	1.00	*A-*
Cheilio inermis	52	0.13 ± 0.06	0.04 - 0.33	27.7 ± 0.60	18.5 - 36.4	3.2	2.7	0.86	*A-*
Calotomus carolinus	10	0.31 ± 0.23	0.11 - 0.90	24.3 ± 1.70	17.6 - 36.9	1.5	2.7	0.97	*A-*
Lethrinus olivaceus	24	0.45 ± 0.46	0.07 - 1.44	30.8 ± 2.14	17.3 - 51.0	1.6	2.9	0.95	*A-*
Priacanthus harmrur	11	0.24 ± 0.11	0.06 - 0.40	25.6 ± 1.96	12.0 - 36.5	50.4	1.9	0.87	*A-*
Halichoeres hortulanus	21	0.13 ± 0.05	0.05 - 0.24	20.9 ± 0.72	14.9 - 28.7	5.7	2.5	0.93	*A-*

Table 2. Mean seasonal condition factor (K) ± standard error (S.E), range and ANOVA values for the 30 species sampled during the survey period. (Use of * indicates significant difference in the mean seasonal condition factor at p < 0.05).

Species	Condition Factor (*K*) for NEM		Condition Factor (*K*) for SEM		
	Mean ±S.E	Range	Mean ±S.E	Range	ANOVA
*Siganus sutor**	1.2 ± 0.01	0.19 - 2.70	1.39 ± 0.02	0.90 - 2.40	*F* = 70.15, *p* = 0.00
*Lethrinus borbonicus**	1.68 ± 0.03	0.17 - 7.17	1.84 ± 0.04	0.76 - 4.25	*F* = 10.20, *p* = 0.00
*Lethrinus lentjan**	1.46 ± 0.02	0.52 - 2.52	1.60 ± 0.02	1.01 - 4.00	*F* = 23.29, *p* = 0.00
*Lutjanus fulviflamma**	1.50 ± 0.03	0.17- 2.85	1.63 ± 0.03	0.57 - 3.42	*F* = 9.48, *p* = 0.00
Leptoscarus vaigiensis	1.65 ± 0.04	0.59 - 5.63	1.72 ± 0.02	0.66 - 2.68	*F* = 2.35, *p* = 0.13
*Scolopsis bimaculatus**	1.61 ± 0.04	0.58 - 4.00	1.44 ± 0.02	1.16 - 1.69	*F* = 5.31, *p* = 0.02
Parupeneus heptacanthus	1.41 ± 0.03	0.68 - 2.62	1.37 ± 0.48	0.71 - 1.69	*F* = 0.38, *p* = 0.54
Lethrinus microdon	1.37 ± 0.08	0.06 - 6.52	1.18 ± 0.05	0.80 - 1.93	*F* = 2.05, *p* = 0.16
*Lethrinus miniatus**	1.55 ± 0.04	0.13 - 2.70	1.88 ± 0.12	1.09 - 4.41	*F* = 10.76, *p* = 0.00
Siganus canaliculatus	1.29 ± 0.03	0.89 - 2.04	1.36 ± 0.03	0.78 - 1.85	*F*=2.97, *p* = 0.09
Scolopsis ghanam	1.59 ± 0.04	1.00 - 2.56	1.66 ± 0.66	0.69 - 3.19	*F* = 0.99, *p* = 0.32
Parupeneus barberinus	1.32 ± 0.04	1.00 - 3.15	1.49 ± 0.09	0.87- 2.99	*F* = 3.93, *p* = 0.05
Scarus ghobban	1.74 ± 0.08	1.31 - 4.86	1.73 ± 0.02	1.31 - 2.11	*F* = 0.01, *p* = 0.93
*Plectorhinchus gaterinus**	2.82 ± 0.16	1.22 - 4.52	1.70 ± 0.04	0.84 - 2.26	*F* = 38.48, *p* = 0.00
Parupeneus macronema	1.46 ± 0.05	1.09 - 2.81	1.38 ± 0.08	0.61 - 1.89	*F* = 0.76, *p* = 0.39
Plectorhinchus chubbi	1.29 ± 0.06	0.14 - 2.12	1.43 ± 0.08	0.13 - 2.78	*F* = 2.01, *p* = 0.16
*Geres oyena**	1.36 ± 0.04	0.75 - 2.35	2.98 ± 0.17	0.96 - 5.78	*F* = 56.67, *p* = 0.00
Siganus luridus	1.51 ± 0.07	0.93 - 2.37	1.47 ± 0.05	1.08 - 1.81	*F* = 0.18, *p* = 0.68
Plectorhinchus flavomaculatus	1.75 ± 0.18	0.89 - 4.83	1.61 ± 0.07	1.12 - 2.53	*F* = 0.54, *p* = 0.47
*Lethrinus harak**	1.37 ± 0.03	0.94 - 1.80	1.54 ± 0.04	0.89 - 3.29	*F* = 5.66, *p* = 0.02
*Hemiramphus far**	0.37 ± 0.01	0.29 - 0.45	0.34 ± 0.01	0.20 - 0.43	*F* = 5.49, *p* = 0.02
Lethrinus mahsena	1.84 ± 0.20	1.50 - 4.26	1.66 ± 0.05	0.84 - 2.96	*F* = 1.70, *p* = 0.20
Lutjanus argentimaculatus	1.50 ± 0.10	1.20 - 2.82	1.40 ± 0.04	0.68 - 1.73	*F* = 1.62, *p* = 0.21
Pomacanthus imperator	3.14 ± 0.12	2.15 - 3.87	3.11 ± 0.05	2.47 - 3.78	*F* = 0.11, *p* = 0.74
*Scarus psittacus**	1.57 ± 0.07	1.05 - 1.80	1.96 ± 0.07	1.35 - 3.02	*F* = 11.43, *p* = 0.00
Cheilio inermis	0.56 ± 0.03	0.39 - 0.87	0.59 ± 0.03	0.25 -1.84	*F* = 0.25, *p* = 0.62
Calotomus carolinus	1.90 ± 0.07	1.42 - 2.26	1.96 ± 0.10	1.50 - 2.44	*F* = 0.30, *p* = 0.59
Priacanthus harmrur	1.35 ± 0.11	0.95 - 2.30	1.48 ± 0.19	0.82 - 3.18	*F* = 0.35, *p* = 0.56
Halichoeres hortulanus	1.45± 0.07	1.18 - 2.20	1.38 ± 0.05	0.93 - 1.69	*F* = 0.74, *p*= 0.40
Lethrinus olivaceus	1.16 ± 0.04	1.03 - 1.33	1.16 ± 0.02	1.01 - 1.35	*F* = 0.00, *p* = 0.99

Discussion

The coefficient of determination, *r*, of the fish species was high during the two seasons indicating a proportional increase in weight and length. This is in agreement with a study done for other species by Oribhabor *et al*. (2011) in the Niger Delta mangrove creek. The significant differences of the average '*b*' values from 3 estimated during the two studied seasons follow the findings of Muto *et al*. (2000). The mean '*b*' values of 2.63 during the NEM and 2.73 during the SEM reported for this study does not deviate from the value of 2.8 reported by Abdurahiman *et al*. (2004) showing that the results are genuine. Allometry could be an indication of large sized fish changing their body form to be more elongated (King, 1996) or that small sized fish were in better nutritional condition during sampling (Froese, 2006).

The estimated '*b*' values for the two seasons revealed that most species exhibited negative allometric growth showing that the length of fish increased more than their weight (Wootton, 1990) and the fish became slender as they increased in length (Pauly, 1984), hence not conforming to the cubic law (Wootton, 1990). The negative allometric growth estimates agree with the findings for *Carlarius heudelotii* in the gulf of Guinea (Ndome *et al*., 2012) and those for *Sparus auratus*, *Diplodus annularis* and *Pagellus erythrinus* (Cherif *et al*., 2008). Letourneur (1998), in his study at Rèunion Island, found a positive allometric result ($b = 3.381$) for *P. macronema*. However, this study recorded negative allometric results (2.6 during the NEM and 2.9 during the SEM) for *P. macronema*.

This study recorded positive allometric results for *P. gaterinus*, *Geres oyena* and *C. inermis* during the NEM, and *P. heptacanthus* and *S. luridus* during the SEM, indicating the species became heavier as they grew longer (Thakur and Das, 1974). Cherif *et al.* (2008) recorded similar results for *Mullus barbatus*, *Merluccius merluccius* and *Scomber scombrus.* Isometric growth was observed for *L. harak*, *H. far*, *and P. imperator* during the NEM, and *L. fulviflamma* during the SEM, respectively. This shows that the weight of these species does not increase faster than the cube of their lengths, hence they follow Le Cren's cubic law. These results also indicate that small sized fish had the same form and were in the same condition as large sized fish (Froese, 2006). Further, the environment was conducive for these species during the two seasons. During this study isometric results were recorded for *L. harak*, *P. imperator*, *H. far* (NEM) and *L. fulviflamma* (SEM). Similar results have been recorded for *Lithognathus mormyrus*, *Boops boops*, *Spicaramaena*, *Trachurus trachurus* and *Trachurus mediterranus* in the Gulf of Tunis (Cherif *et al*., 2008). The isometric result for *P. imperator* also conforms to that recorded in FishBase (Froese and Pauly, 2016).

According to Fulton (1902) a standard condition factor of 1.6 implies excellent condition, 1.4 - good and well-proportioned fish, 1.2 - fair condition, 1 - a long and thin fish in poor condition, and 0.8 - extremely poor condition. From this study *H. far* (mean = 0.37, S.E = 0.01 NEM; mean = 0.34, S.E = 0.01 SEM) and *C. inermis* (mean = 0.56, S.E = 0.03 NEM; and mean = 0.59, S.E = 0.03 SEM) had a mean condition factor of less than 1 indicating that the health of these species in the marine environment is challenged. The other species had a mean condition factor above 1 indicating that the fish species were doing well in the marine environment during the NEM and SEM seasons. However, there was a significant difference in the mean condition factor for 11 species during the two seasons ($P < 0.05$) which could be attributed to variations in body weight of the fish during the two study seasons. The low condition factor values for *S. sutor*, *L. borbonicus*, *L. lentjan*, *L. fulviflamma*, *G. oyena*, *Lethrinus miniatus* and *Lethrinus harak* during the NEM could be attributed to stress related factors such as inadequate food and competition for resources. The use of total weight instead of eviscerated weight may have introduced important bias in the analyses as variations in gonads and gut contents in different seasons may greatly confound the results obtained. Therefore, we recommend that future studies consider evisceration of the fish samples before conducting length weight analyses for comparisons.

Conclusion

This study provides information on the seasonal variation in length–weight relationship and condition factor for species usually encountered in Kenya artisanal fisheries. These results are useful in providing data for stock assessment and estimation of weights for the marine artisanal fisheries in Kenya. The findings from this study are also useful for comparison with the results of other studies undertaken during different seasons and at different localities.

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References

Abdurahiman KP, Nayak TH, Zacharia PU, Mohamed KS (2004) Length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India. NAGA, World Fish Centre Quarterly 27 (1, 2): 9-14

Anam R, Mostarda E (2012) Field identification guide to the living marine resources of Kenya. FAO, 357 pp

Aura CM, Munga CN, Kimani E, Manyala JO, Musa SF (2011) Scientific Note Length-Weight Relationships for Nine Deep Sea Fish Species off the Kenyan Coast. Pan-American Journal of Aquatic Sciences 6 (2): 188-192

Cherif M, Zarrad R, Gharbi H, Missaoui H, Jarboui O (2008) Length-weight relationships for 11 fish species from the Gulf of Tunis (SW Mediterranean Sea, Tunisia). Pan-American Journal of Aquatic Sciences 3 (1): 1-5

Duarte JO, Garcia CB, Sandoval N, von Schiller D, Melo G, Navajas P (1999) Length–weight relationships of demersal fishes from the Gulf of Salamanca, Colombia. Naga, the ICLARM Quarterly 22 (1): 34-36

Froese R (2006) Cube law, condition factor and weight-length relationship: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22 (4): 24-253

Froese R, Pauly D (2016) FishBase. Worldwide electronic publication. http://www. Fishbase org. version (10/2015)

Fulton T (1902) Rate of growth of sea-fishes. Report of the Fisheries Board of Scotland 20: 1-22

Haimovici M, Velasco CG (2000) Length–weight relationship of marine fishes from Southern Brazil. URI: http://repositorio.furg.br/handle/1/2458

King RP (1996) Length–weight relationships of Nigerian coastal water fishes. Naga, the ICLARM Quarterly 19 (4): 53-58

Le Cren ED (1951) The length-weight relationship and seasonal cycle in weight and seasonal cycle in weight and condition in perch, *Perca fluviatilis* from the opercular bone. Journal of Animal Ecology 20: 201-219

Letourneur Y (1998) Length–weight relationship of some marine fish species in Réunion Island, Indian Ocean. Naga, the ICLARM Quarterly 21 (4): 37-39

Lieske E, Myers R (2001) Collins Pocket Guide to Coral Reef Fishes: revised edition. Publishers: Princeton University Press, 400 pp

Mbaru EK, Mlewa CM, Kimani EN (2010) Length–weight relationship of 39 selected reef fishes of the Kenyan coastal artisanal fishery. Fisheries Research 106 (3): 567 – 569 [doi:org/10.1016/j.fishres.2010.09.012]

McClanahan TR (1988) Seasonality in East Africa's coastal waters. Inter-Research F. R. Germany. Marine Ecological Progress Series 44: 191-199

Muto EY, Soares LSH, Wongtschowski CLDBR (2000) Length–weight relationship of marine fish species off São Sebastião system, São Paulo, southeastern Brazil. Naga, the ICLARM Quarterly 23 (4): 27-29

Ndome CB, Eteng AO, Ekanem AP (2012) Length-weight relationship and condition factor of the smooth mouth marine catfish (*Carlarius heudelotii*) in the gulf of Guinea, Niger delta, Nigeria. AACL Bioflux 5 (3): 163-167

Oribhabor BJ, Ogbeibu AE, Udo MT (2011) The length-weight relationships of brackish water/marine fish species assemblage in a Niger Delta Mangrove Creek, Nigeria. Current Research Journal of Biological Sciences 3 (6): 616-621

Pauly D (1984) Fish population dynamics in tropical waters: a manual for use with programmable calculators (vol. 8). WorldFish

Ricker WE (1975) Computation and interpretation of biological statistics of fish population. Bulletin of the Fishery Research Board of Canada 191: 1-382

Sparre P, Venema SC (1998) Introduction to tropical fish stock assessment. Manual 1. FAA Fisheries Technical paper 306/1. 407 pp

Thakur NK, Das MK (1974) Length-weight relationship of Heteropneustes fossils (Bloch). Journal of Inland Fish Society India 6: 95-99

Wootton RJ (2012) Ecology of teleost fishes. Springer Science and Business Media. 386 pp

Marine Biodiversity of La Reunion Island: Echinoderms

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Abstract

The inventories of marine species of La Reunion (South West Indian Ocean) are still incomplete for several phylum including the Echinodermata. The present knowledge for the five classes is reported here, in the habitats below (1) and above (2) 50 m depth. The overall diversity for (1) is 136 species and for (2), 48 species. On the whole, as in the broader western Indian Ocean, the Holothuroidea and the Ophiuroidea are the dominant classes. Several new species have been described and many still need further research.

Keywords: sea stars, brittle stars, sea urchins, sea cucumbers, feather stars, SWIO

Introduction

The South West Indian Ocean (SWIO) is recognized as one of the marine biodiversity hotspots in the world, because of high species richness and endemism (Roberts *et al.*, 2002). While fishes and corals have long been well documented from this area, other groups such as Echinoderms needed further attention. Echinoderms are a very distinct five-rayed phylum, very important in marine communities where they play critical roles (Purcell *et al.*, 2016). The five extant classes, namely Asteroidea (sea stars), Ophiuroidea (brittle stars), Echinoidea (sea urchins), Holothuroidea (sea cucumbers) and Crinoidea (feather stars) account for more than 7 000 described species for the world's oceans (Byrne and O' Hara, 2017).

Previous studies had been conducted in several countries or islands of the SWIO region, on one class, as for example for the holothurians (Conand and Muthiga, 2007; Muthiga and Conand, 2014; Conand, 2008; Eriksson *et al.*, 2015; Samyn *et al.*, 2006; Samyn and Tallon, 2005; FAO, 2013), for the ophiuroids (Stohr *et al.*, 2008; Hoareau *et al.*, 2013; Boissin *et al.,* 2016; Boissin *et al.*, 2017), and the asterids (Jangoux and Aziz, 1988; O'Loughlin and McKenzie, 2013). Other studies have focused on the whole phylum in the region (Clark and Rowe, 1971; Rowe and Richmond, 2011), or groups of islands, such as the French programme BIORECIE on the Îles Eparses (or Scattered islands) (Conand *et al.*, 2010; Mulochau *et al,* 2014; Conand *et al.*, 2015).

The current knowledge on the diversity of the Echinoderms from La Reunion are reported in this paper. This young volcanic island (21.115°S and 55.536°E), is situated 800 km east of Madagascar. Its marine biodiversity needs to be evaluated given the increases of natural and man-induced threats on the narrow fringing reefs, and the high density of human population. The Echinoderms have been studied during the last forty years and several publications report the ecology of reef populations for several abundant species of the different classes.

The whole phylum has also been focused on in different programmes conducted during this period, such as BIOTAS (ANR-06-BDIV-002) (Hoareau *et al.* 2013; Boissin *et al.,* 2016; Boissin *et al*., 2017), and BIOLAVE, on the underwater lava flows of the volcano Piton de la Fournaise (Bollard *et al.,* 2013). Recently, the book 'Oursins, Etoiles de mer & autres échinodermes' (2016) has been published in French by the authors of the present paper, with many photos and details. It is important to present this updated inventory to the scientific audience and therefore assist in identifying new species and allow comparisons with other islands or countries in the SWIO.

Methods

The data from the previous publications on the different classes have been gathered and updated.

The first inventory in English is presented here, for the five Echinoderm classes, taking into account the littoral zone, to about 50 m depth, explored by free or scuba diving (1), and deeper zones on the reef-slopes to about 1 000 m (2) which were earlier explored during different cruises by dredging, such as 'MD32' with the 'Marion Dufresne' (1982), and the La Reunion Aquarium team with the 'Explorer' (2011-2014). The species validity has been checked using Miller *et al.* (2017), Stöhr *et al*. (2016) and WoRMS (2018).

Results

Echinoderm diversity

The overall diversity for the Echinoderms of La Reunion is presented in Table 1.

The total number of species presently identified is 184; 4 specimens are identified at the genus level. The total number of littoral species (1) is 136, while the number of the deep species (2) is 48.

Diversity by classes

Asteroidea diversity

Table 2 presents the list of the Asteroidea collected and/or observed. The forty-six species belong to six orders and sixteen families. A few specimens from the family Ophidiasteridae, *Leiaster* and *Ophidiaster,* remain undetermined.

Twenty-two species are from **littoral zones** (Table 2 (1)) collected on the coral reefs or from other sandy and rocky biotopes, but are mostly from sparse individuals. During the BIOLAVE programme, 6 species where collected, including the recently described *Aquilonastra conandae* (Bollard *et al.,* 2013). An *Anthenoides* aff. *marleyi* has been found very well conserved in the stomach of a tiger shark *Galeocerdo cuvier* caught at 25 m depth; it was probably recently ingested as it was intact, while the other preys were partly digested.

A few species have been studied in more detail:
1) *Acanthaster planci* now *mauritiensis* (see discussion). Following observations by divers, a study was undertaken in 1998 based on the results of an inquiry distributed to volunteers. From the 352 forms returned during two years, the observations by Emeras *et al.* (2004) concluded that: 1) the distribution was mostly on the western coast, with 17% on reef flats, 83% on outer slopes, rarely seen under 20 meters; 2) the population densities were low (less than 4 individuals per 30 minutes dive) and declining from year 2000; 3) the modal size of the individuals was large (40 cm diameter). Only anecdotal observations have been made on the species in La Reunion since that study.

Table 1. Echinodermata from La Réunion. Number of species in each class in the littoral zone (1) and the deeper zone (2). 'Ni' is number of genera with unidentified species.

	No. spp Littoral (1)	Ni spp Littoral	No. spp Deep (2)	Ni spp Deep	Total + Ni
Asteroidea	22	1	24	1	46 +2
Ophiuroidea	38	1	16		54 +1
Echinoidea	34		7		41
Holothuroidea	38	1			38 +1
Crinoidea	4		1		4 +1
Total	136	3	48	1	184 +4

Table 2. Asteroidea from La Réunion.

Order	Family	Species	Depth
Brisingida	Brisingidae	*Brisinga aff. panopla* Fisher, 1906	2
Forcipulatida	Asteriidae	*Coronaster volsellatus* (Sladen, 1889)	1
	Zoroasteridae	*Zoroaster carinatus* Alcock, 1893	2
Notomyotida	Benthopectinidae	*Cheiraster Reunionensis* Jangoux & Aziz, 1988	2
Paxillosida	Astropectinidae	*Astropecten bengalensis* (Döderlein, 1917)	2
		Astropecten exilis Mortensen, 1933	2
		Astropecten granulatus natalensis John, 1948	2
		Astropecten hemprichi Müller & Troschel, 1842	2
		Astropecten leptus H.L. Clark, 1926	2
		Astropecten longibrachius Jangoux & Aziz, 1988	2
		Astropecten polyacanthus (Müller & Troschel, 1842)	1
		Ctenophoraster diploctenius Fisher, 1913	2
		Persephonaster exquisitus Jangoux & Aziz, 1988	2
	Luidiidae	*Luidia avicularia* Fisher, 1913	2
Valvatida	Acanthasterdidae	*Acanthaster brevispinnus* Fisher, 1917	2
		Acanthaster mauritiensis de Loriol, 1885*	1
	Asterinidae	*Aquilonastra conandae* (O'Loughlin & Rowe, 2006)	1
		Aquilonastra richmondi (O'Loughlin & Rowe, 2006)	1
		Aquilonastra samyni (O'Loughlin & Rowe, 2006)	1
		Aquilonastra aff. watersi O'Loughlin & Rowe, 2006	1
		Tegulaster leptalacantha (H.L. Clark, 1946)	2
	Asteropseidae	*Asteropsis carinifera* (Lamarck, 1816)	1
		Valvaster striatus (Lamarck, 1816)	1
	Goniasteridae	*Anthenoides cristatus* (Sladen, 1889)	2
		Anthenoides aff. marleyi Mortensen, 1925	1
		Fromia indica (Perrier, 1869)	1
		Fromia milleporella (Lamarck, 1816)	1
		Fromia monilis (Perrier, 1869)	1
		Mediaster ornatus Fisher, 1906	2
		Ogmaster capella (Müller & Troschel, 1842)	2
		Plinthaster doederleini (Koehler, 1909)	2
		Stellaster equestris (Retzius, 1805)	2
	Leilasteridae	*Leilaster spinulosus* Aziz & Jangoux, 1985	2
	Mithrodiidae	*Mithrodia clavigera* (Lamarck, 1816)	1

Order	Family	Species	Depth
Valvatida	Ophidiasteridae	*Cistina columbiae* (Gray, 1840)	1
		Dactylosaster cylindricus (Lamarck, 1816)	1
		Ferdina flavescens Gray, 1840	1
		Linckia guildingi Gray, 1840	1
		Linckia multifora (Lamarck, 1816)	1
		Nardoa variolata (Retzius, 1805)	1
	Oreasteridae	*Astrosarkus idipi* Mah, 2003	1
		Culcita schmideliana (Retzius, 1805)	1
	Poraniidae	*Marginaster paucispinus* Fisher, 1913	2
Velatida	Pterasteridae	*Calyptraster gracilis* Jangoux & Aziz, 1988	2
		Euretaster cribrosus (von Martens, 1867)	2
		Hymenaster aff. bartschi Fisher, 1916	2

**Acanthaster mauritiensis* replaces *Acanthaster planci* (see text)

2) *Acanthaster brevispinnus* has been observed and filmed in 2001, as a dense population at 40 m depth at the foot of the reef-slope of St Gilles. Despite several dives at the site afterwards, it has not been seen again, suggesting a rapid migration.

3) Several species of Asterinidae have been collected on La Reunion reef flats. A first study was undertaken to determine the modalities of the asexual reproduction by fission and regeneration of an abundant species from the outer reef flat (Kojadinovic *et al.,* 2004) which was later described as *Aquilonastra conandae* (O'Loughlin and Rowe, 2006) and is endemic to the island. These authors identified three other species of *Aquilonastra* from La Reunion also present in the WIO. The sexual reproduction of *Aquilonastra conandae* shows a seasonal gametogenesis with large oocytes suggesting direct development (Ooka *et al.*, 2010).

Half of the species come from **deeper zones** (Table 2 (2)).

Several species were collected during the MD2 cruise in 1982 and identified by Jangoux and Aziz (1988). They described several new species, as *Cheiraster Reunionensis, Astropecten longibrachius, Persephonaster exquisitus, Leilaster spinulosus,* and *Calyptraster gracilis.*

Echinoidea diversity

Table 3 presents the list of the Echinoidea collected and/or observed. The thirty-four species belong to eight orders and sixteen families. Most have been collected in littoral zones on coral reefs and sandy bays (Table 3 (1). During the BIOLAVE programme, 10 species were identified (Bollard *et al.,* 2013).

The biology of some abundant populations important in ecosystem functioning has been studied in detail.
1) *Echinometra mathaei* and *Echinometra mathaei oblonga* present dense populations which play an important role as grazers in the carbonate budget. In La Reunion, they are major eroders on the outer reef flat at one site, with CaCO3= 8kg m-2. Y-1 (Conand *et al.,* 1997b). A further comparison with other sites of different eutrophication levels shows large differences in urchin sizes and densities and therefore in bioerosion rates, and a clear gradient from the back-reef to the outer reef on the non-degraded sites (Conand *et al.,* 1998; Peyrot-Clausade *et al.,* 2000).

2) *Tripneustes gratilla* is one of the most common herbivorous sea urchin on La Reunion reefs with densities up to 5 individuals. m-2 (Naim *et al.,* 1997). It was selected for studying carbon and nitrogen cycling. Its feeding rythms showed two periods of maximum ingestion (before dawn and after sunset) and a minimum near midday (Lison de Loma *et al.,* 1999). Its diet was mainly algae, with a strong selectivity for *Turbinaria ornata* and avoidance for other species, but with differences between sites (Lison de Loma *et al.,* 2002).

Table 3. Echinoidea from La Réunion.

Order	Family	Species	Depth
Cidaroida	Cidaridae	*Eucidaris metularia* (Lamarck, 1816)	1
		Phyllacanthus imperialis (Lamarck, 1816)	1
		Stereocidaris indica Döderlein, 1901	2
		Stylocidaris badia (H.L. Clark, 1925)	2
Echinothurioida	Echinothuriidae	*Asthenosoma marisrrubri* Weinberg and de Ridder 1998 *	1
	Diadematidae	*Astropyga radiata* (Leske, 1778)	1
		Diadema setosum (Leske, 1778)	1
		Diadema savignyi (Michelin, 1845)	1
		Diadema paucispinum (Agassiz, 1863)	1
		Echinothrix calamaris (Pallas, 1774)	1
		Echinothrix diadema (Linnaeus, 1758)	1
		Lissodiadema lorioli Mortensen, 1903	1
Camarodonta	Echinometridae	*Colobocentrotus (Podophora) atratus* (Linnæus, 1758)	1
		Echinometra mathaei (Blainville, 1825)	1
		Echinometra oblonga (Blainville, 1825)	1
		Echinostrephus molaris (Blainville, 1825)	1
		Heterocentrotus mamillatus (Linnaeus, 1758)	1
		Heterocentrotus trigonarius (Lamarck, 1816)	1
	Toxopneustidae	*Nudechinus verruculatus* (Lütken, 1864)	1
		Pseudoboletia maculata Troschel, 1869	1
		Pseudoboletia indiana (Michelin, 1862)	1
		Toxopneustes pilleolus (Lamarck, 1816)	1
		Tripneustes gratilla (Linnæus, 1758)	1
Stomopneustoida	Stomopneustidae	*Stomopneustes variolaris* (Lamarck, 1816)	1
Holasteroida	Calymnidae	*Sternopatagus sibogae* de Meijere, 1904	2
Spatangoida	Brissidae	*Brissopsis luzonica* (Gray, 1851)	1
		Brissus latecarinatus (Leske, 1778)	1
		Metalia dicrana H.L. Clark, 1917	1
		Metalia spatagus (Linnæus, 1758)	1
		Metalia sternalis (Lamarck, 1816)	1
	Loveniidae	*Lovenia elongata* (Gray, 1845)	2
	Maretiidae	*Maretia planulata* (Lamarck, 1816)	1
	Schizasteridae	*Schizaster gibberulus* L. Agassiz & Desor, 1847	1
Echinoneoida	Echinoneidae	*Echinoneus cyclostomus* Leske, 1778	1

Order	Family	Species	Depth
Clypasteroida	Astriclypeidae	*Sculpsitechinus auritus* (Leske, 1778)	2
		Echinodiscus bisperforatus Leske, 1778	1
	Clypasteridae	*Clypeaster reticulatus* (Linnæus, 1758)	1
	Echinocyamidae	*Echinocyamus megapetalus* H.L. Clark, 1914	1
	Laganidae	*Jacksonaster depressum* (L. Agassiz, 1841)	1
		Laganum decagonale (Blainville, 1827)	2
	Periscomidae	*Pericosmus macronesius* Koehler, 1914	2

* *Asthenosoma varium* (Grube 1868) has been replaced by *A. marisrubri* after checking by the authors

3) *Colobocentrotus (Podophora) atratus* dense populations on the wave swept intertidal basaltic rocks (Santos and Flammang, 2008); the annual reproduction is during the warm season but its recruitment in this extreme environment needs more studies (Conand, 2001).

4) A few Echinothuriid *Asthenosoma* were collected, they were first listed as *A. varium* Grube, 1868, but are probably *A. marisrubri* (Weinberg and De Ridder, 1998), a species described as endemic to the Red Sea; one specimen was found at 80m depth near St Gilles, one juvenile came from BIOLAVE; it has also been collected near Madagascar during the MIRIKY cruise. These observations extend its distribution in the WIO significantly.

A few species came from local dredging at depths of over 100 meters (Table 3 (2), but no data from MD32 has yet been published.

Ophiuroidea diversity

Table 4 presents the list of the Ophiuroidea collected and/or observed. The fifty-four species belong to seven orders and thirteen families.

In La Reunion, this class was first been studied by Guille & Ribes (1981) who reported 21 species associated with scleractinian corals from La Saline on the west coast. In 1984, 20 species collected from deep water by the 'Marion Dufresne' cruise in 1982 were reported by Vadon & Guille (1984). The only species in common between these two studies was *Ophiolepis irregularis*. More recently, non-focal sampling and the description of *Ophiocanops multispina* Stöhr, Conand & Boissin, 2008 raised the known fauna to 45 species, 26 of which were recorded from shallow waters (Stöhr *et al.*, 2008). From the BIOLAVE programme, 13 species were identified from 8 genera including juveniles, which made the ophiuroids the more diverse class of echinoderms in Reunion (Bollard *et al.,* 2013). Recently, Boissin *et al.* (2016) presented the results of extensive sampling in shallow water reef ophiuroids and a DNA barcoding study of SWIO brittle-stars revealed that up to 20% of ophiuroid biodiversity might still be unknown (Boissin *et al.*, 2017). The new classification of higher taxa in Ophiuroidea by O'Hara *et al.* (2018) has been followed in this paper. Noticeably, regarding the superorder Ophintegrida, *Ophiopeza* is in a new family Ophiopezidae that belongs together with Ophiocomidae, Ophiodermatidae and Ophiomyxidae to the order Ophiacanthida, suborder Ophiodermatina. Ophiotrichidae, Ophiactidae and Amphiuridae belong to the order Amphilepidida, suborder Gnathophiurina, while Ophionereididae and Ophiolepididae belong to the suborder Ophionereidina. Regarding the superorder, Euryophiurida, Gorgonocephalidae and Euryalidae belong to the order Euryalida, while Ophiuridae belongs to Ophiurida.

The littoral species are presented in Table 4 (1) and the deeper species in Table 4 (2).

Holothuroidea diversity

Table 5 presents the list of the littoral Holothuroidea collected and/or observed. The thirty-eight species belong to four orders and five families. Several specimens from the genera *Holothuria (Stauropora), Stichopus, Leptosynapta* and *Polylectana* are not yet determined to species level.

Several programmes, first supported by The Regional Council of La Reunion (Conand & Mangion, 2002; Conand *et al.,* 2003), then WIOMSA (Conand and Frouin, 2007), BIOLAVE where only 5 species were identified (Bollard *et al.,* 2013), and BIOTAS (Conand *et al.,*

Table 4. Ophiuroidea from La Réunion.

Order	Family	Species	Depth
Euryalida	Euryalidae	*Asterostegus tuberculatus* Mortensen, 1933	2
	Gorgonocephalidae	*Astroboa nuda* (Lyman, 1874)	1
Ophiurida	Ophiuridae	*Amphiophiura bullata convexe* (Lyman, 1878)	2
		Amphiophiura paupera (Koehler, 1897)	2
		Amphiophiura sculptilis (Lyman, 1878)	2
		Anthophiura ingolfi Fasmer, 1930	2
		Ophiomastus platydiscus H.L. Clark, 1939	2
		Ophiophyllum borbonica Vadon & Guille, 1984	2
		Ophioplinthus abyssorum (Lyman, 1883)	2
		Ophiotypa simplex Koehler, 1897	2
		Ophiura aequalis (Lyman, 1878)	2
		Ophiura irrorata (Lyman, 1878)	2
		Ophiura irrorata loveni (Lyman, 1878)	2
		Ophiura kinbergi Ljungman, 1866	2
		Perlophiura profundissima Belyaev & Litvinova, 1972	2
		Uriopha ios Paterson, 1980	2
Amphilepidida	Amphiuridae	*Amphioplus* sp.	1
		Amphipholis squamata (Delle-Chiaje, 1828)	1
		Amphiura crispa Mortensen, 1940	1
		Ophiocentrus aspera (Koehler, 1905)	2
	Ophiactidae	*Ophiactis lymani* Ljungman, 1872	1
		Ophiactis modesta Brock, 1888	1
		Ophiactis picteti (De Loriol, 1893)	1
		Ophiactis quadrispina H.L. Clark, 1915	1
		*Ophiactis savignyi (*Müller & Troschel, 1842)	1
	Ophionereididae	*Ophionereis porrecta* Lyman, 1860 sp1	1
		Ophionereis porrecta Lyman, 1860 sp2	1
	Ophiotrichidae	*Macrophiothrix* aff. *belli* (Döderlein, 1896)	1
		*Macrophiothrix longipeda (*Lamarck, 1816)	1
		Macrophiothrix aff. *paucispina* Hoggett, 1991	1
		Macrophiothrix propinqua (Lyman, 1861)	1
		Macrophiothrix robillardi (De Loriol, 1893)	1
		Ophiothela aff. *danae* Verrill, 1869	1
		Ophiothrix foveolata Marktanner-Turneretscher, 1887	1
		Ophiothrix trilineata trilineata Lütken, 1869	1

Order	Family	Species	Depth
Amphilepidida	Ophiolepididae	*Ophiolepis cincta* Müller & Troschel, 1842 complex sp1	1
		Ophiolepis cincta Müller & Troschel, 1842 complex sp2	1
		Ophiolepis irregularis Brock, 1888	1
		Ophiolepis superba H.L. Clark, 1915	1
		Ophiomusium luetkeni Lyman, 1878	2
		Ophiomusium lymani Wyville-Thomson, 1873	2
		Ophiomusium scalare Lyman, 1878	2
		Ophioplocus imbricatus Müller & Troschel, 1842	1
		Ophiosphalma fimbriatum (Koehler, 1922)	2
		Ophiosphalma planum (Lyman, 1878)	2
Ophiacanthida	Ophiacanthidae	*Ophiacantha funebris* (Koehler, 1930)	2
		Ophiacantha pentagona Koehler, 1897	2
	Ophiomyxidae	*Neoplax ophiodes* Bell, 1884	1
		Ophiocanops multispina Stohr Conand et Boissin, 2008	1
		Ophiomyxa compacta (Koehler, 1905)	2
	Ophiocomidae	*Ophiocoma brevipes* Peters, 1851	1
		Ophiocoma cynthiae Benavides-Serrato & O'Hara, 2008	1
		Ophiocoma dentata Müller & Troschel, 1842	1
		Ophiocoma doederleini De Loriol, 1899	1
		Ophiocoma erinaceus Müller & Troschel, 1842	1
		Ophiocoma krohi Stöhr Boissin & Hoareau, 2013	1
		Ophiocoma pica Müller & Troschel, 1842	1
		Ophiocoma pusilla (Brock, 1888)	1
		Ophiocoma scolopendrina (Lamarck, 1816)	1
		Ophiocomella sexradia (Duncan, 1887)	1
		Ophiopsila pantherina Koehler, 1898	1
	Ophiodermatidae	*Ophiarachnella aff. gorgonia* (Müller & Troschel, 1842)	1
		Ophiarachnella septemspinosa (Müller et Troschel, 1842)	1
		Ophioconis cupida Koehler, 1905	1
	Ophiopezidae	*Ophiopeza fallax fallax* Peters, 1951	1
		Ophiopeza spinosa (Ljungman, 1867)	1

Table 5. Holothuroidea from La Réunion.

Order	Family	Species	Depth
Aspidochirotida * othuriida *	Holothuriidae	*Actinopyga capillata* Rowe & Massin, 2006	1
		Actinopyga aff. *echinites* (Jaeger, 1833)	1
		Actinopyga mauritiana (Quoy & Gaimard, 1834)	1
		Actinopyga aff. *obesa* (Selenka, 1867)	1
		Bohadschia subrubra (Quoy & Gaimard, 1834)	1
		Bohadschia vitiensis (Semper, 1867)	1
		Holothuria (Cystipus) inhabilis Selenka, 1867	1
		Holothuria (Lessonothuria) insignis Ludwig, 1875	1
		Holothuria (Halodeima) atra Jaeger, 1833	1
		Holothuria (Lessonothuria) lineata Ludwig, 1875	1
		Holothuria (Lessonothuria) pardalis Selenka, 1867	1
		Holothuria (Lessonothuria) verrucosa Selenka, 1867	1
		Holothuria (Mertensiothuria) hilla Lesson, 1830	1
		Holothuria (Mertensiothuria) leucospilota (Brandt, 1835)	1
		Holothuria (Microthele) aff. *fuscogilva* Cherbonnier, 1980	1
		Holothuria (Microthele) nobilis (Selenka, 1867)	1
		Holothuria (Platyperona) difficilis Semper, 1868	1
		Holothuria (Semperothuria) cinerascens (Brandt, 1835)	1
		Holothuria (Semperothuria) flavomaculata Semper, 1868	1
		Holothuria (Stauropora) fuscocinerea Jaeger, 1833	1
		Holothuria (Stauropora) pervicax Selenka, 1867	1
		Holothuria (Theelothuria) turriscelsa Cherbonnier, 1980	1
		Holothuria (Thymiosycia) arenicola Semper, 1868	1
		Holothuria (Thymiosycia) impatiens (Forskål, 1775) complex sp.1	1
		Holothuria (Thymiosycia) impatiens (Forskål, 1775) complex sp.2	1
		Labidodemas pertinax (Ludwig, 1875)	1
		Pearsonothuria graeffei (Semper, 1868)	1
Synallactida *	Stichopodidae	*Stichopus chloronotus* Brandt, 1835	1
		Stichopus herrmanni Semper, 1868	1
		Stichopus monotuberculatus (Quoy & Gaimard, 1834)	1
		Stichopus sp	1
		Thelenota ananas (Jaeger, 1833)	1
Apodida	Chiridotidae	*Chiridota stuhlmanni* Lampert, 1896	1
		Polycheira rufescens (Brandt, 1835)	1

Order	Family	Species	Depth
Apodida	Synaptidae	*Euapta godeffroyi* (Semper, 1868)	1
		Opheodesoma grisea (Semper, 1867)	1
		Synapta maculata (Chamisso and Eysenhardt, 1821)	1
Dendrochirotida	Sclerodactylidae	*Afrocucumis africana* (Semper, 1867)	1
		Ohshimella ehrenbergi (Selenka, 1868)	1

* Recent revision by Miller *et al.* 2017

2010) have allowed the biodiversity in La Reunion shallow environments to be recorded. One new species *Actinopyga capillata* has been described from these collections (Rowe and Massin, 2006).

Deeper habitats have not been studied yet.

During recent decades, several studies have also been conducted on the reproductive biology, the ecology and the genetics of several common holothurian species.

The **reproductive biology** has been detailed for several species with dense populations which display seasonal sexual reproduction as well as asexual scission. *Holothuria atra* is the most frequent and abundant Holothuriidae species; the biometry and reproduction have been analyzed at several sites (Conand, 1996; Jaquemet *et al.,*1999; Conand, 2004). *H. leucospilota* is another abundant black littoral species (Conand *et al.,* 1997a; Gaudron *et al.,* 2008).

The **ecological role** through feeding and bioturbation of these two species has been analysed by Mangion *et al.* (2004). The species were more abundant in eutrophic areas where the mixed populations were able to rework 82 kg dry weight.m^{-2}.Y^{-1}. *Stichopus chloronotus* is the most frequent and abundant Stichopodidae on La Reunion reefs. The population parameters and the reproductive strategies have been studied (Conand *et al.*, 1998; Hoareau and Conand, 2001; Conand *et al.,* 2002.)

The population characteristics of these species and *Actinopyga aff echinites*, another abundant species, have been summarized in view of regional management efforts of their populations (Kohler *et al.,* 2009).

A first inventory of **diversity** had been prepared for the Regional Council (Conand *et al.,* 2003) and more recent programmes have allowed completion of the inventory for the littoral areas (Conand *et al.,* 2010). Small and cryptic species still need more investigation and deeper populations are not known.

The first genetic data have been collected through a collaboration with Australia on the fissiparous species *S. chloronotus* and *H. atra* (Uthicke *et al.,* 2001; Uthicke and Conand, 2005). The barcoding has been undertaken and established for several commercial species (Uthicke *et al.,* 2010); it will be important in the future for international regulations of CITES or other regulations.

Crinoidea diversity

Table 6 presents the list of the **Crinoidea** collected and/or observed. The five species belong to the order Comatulidae and three families.

Table 6. Crinoidea from La Réunion.

Order	Family	Species	Depth
Comatulida	Guillecrinidae	*Guillecrinus Reunionensis* Roux, 1985	2
	Colobometridae	*Cenometra aff.emendatrix madagascarensis* AM Clark, 1972	1
	Mariametridae	*Stephanometra indica* (Smith, 1876)	1
		Lamprometra palmata (Muller, 1841)	1
	Tropiometridae	*Tropiometra aff. carinata* (Lamarck, 1816)	1

The littoral species are not very diverse, with only 4 species from 3 families. During the programme BIOLAVE, 2 of these species were found again on the lava flows (Bollard *et al.,* 2013).

For the deeper species, the MD32 cruise was interesting, as the new species (and new gender and family) *Guillecrinus Réunionensis* was described by Roux (1985) and other specimens are still under study.

Discussion

The different classes show the same proportions as reported by Rowe and Richmond (2011) for the whole WIO, with the dominance of the Holothuroidea and Ophiuroidea. The high diversity of Ophiuroidea comes from many deep species collected during the MD32 cruise. The Holothuroidea, given the increasing commercial value of several species (Conand, 2008), have received much attention, with several local studies in the SWIO. Illegal fisheries, not reported to occur in La Reunion, are an important problem, which needs new tools to be documented and managed (Conand, 2017, 2018). The systematics of the Crinoidea is presently being revised, using integrative taxonomy/morphology coupled with genetics. The Crown-of-Thorns (COT) populations (*Acanthaster*, Asteroidea) deserve special monitoring in the context of climate change and numerous recent outbreaks (Pratchett *et al.,* 2017). The species has previously been reported as *A. planci*, but a recent large-scale study by Haszprunar *et al.* (2017) proposes *A. mauritiensis* de Loriol, 1885 for the WIO. *A. mauritiensis* is therefore used before changes are introduced in the main database WoRMS and Asteroidea (Mah, 2018).

Despite the small size of the reef and deeper habitats of La Reunion, a few new species have been collected and identified: 1 Asteroidea *Aquilonastra conandae*, 1 Holothuroidea *Actinopyga capillata,* 2 littoral Ophiuroidea *Ophiocanops multispina,* and *Ophiocoma krohi*, and several specimens still need further studies.

Many species in each class are new records for La Reunion.

Additional sampling over time in the different habitats will be necessary to follow this diversity and to complete this inventory. Since recent inventories coupled with DNA barcoding in the SWIO have shown that biodiversity might be underestimated in the ophiuroids by 20% (but also in other phyla: e.g. hydroid diversity could be underestimated by two thirds (Boissin *et al.* 2018), further inventories on cryptic habitats and specimens of small size will certainly add to these lists. It is also necessary to conserve and protect these echinoderm species that play such critical ecological roles in coral reefs (Purcell *et al.*, 2016).

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References

Boissin E, Hoareau T, Paulay G, Bruggemann H (2016) Shallow-water reef ophiuroids (Echinodermata: Ophiuroidea) of Reunion (Mascarene Islands), with biogeographic considerations. Zootaxa 4098: 273-297 [https://doi.org/10.11646/zootaxa.4098.2]

Boissin E, Hoareau T, Paulay G, Bruggemann H (2017) DNA barcoding of reef brittle stars (Ophiuroidea, Echinodermata) from the southwestern Indian Ocean evolutionary hot spot of biodiversity. Ecology and Evolution 7:11197-11203

Boissin E, Hoareau T, Postaire B, Gravier-Bonnet N, Bourmaud C (2018) Cryptic diversity, low connectivity and suspected human-mediated dispersal among 17 widespread Indo-Pacific hydroid species of the South-western Indian Ocean. Journal of Biogeography (in press)

Bollard S, Pinault M, Quod JP, Boissin E, Hemery L, Conand C (2013) Biodiversity of echinoderms on underwater lava flows with different ages, from the Piton de La Fournaise (Reunion Island, Indian Ocean). Cahiers De Biologie Marine 54: 491-497

Byrne M, O’Hara TD (eds) (2017) Australian Echinoderms: Biology, Ecology & Evolution. CSIRO Publishing, Canberra, 612 pp

Clark AM, Rowe FWE (1971) Monograph of shallow-water Indo-West Pacific echinoderms. Trustees of the British Museum (Natural History), London, 234 pp

Conand C (1996) Asexual reproduction by fission in *Holothuria atra*: Variability of some parameters in populations from the tropical Indo-Pacific. Oceanologica Acta 19 (3): 209-216

Conand C (2001) Biology of a poorly known echinoid, *Colobocentrotus atratus*, inhabiting wave swept intertidal basaltic rocks. In: Barker (ed) Echinoderm 2000, Swets & Zeitlinger, pp 431

Conand C (2004) Monitoring a fissiparous population of *Holothuria atra* on a fringing reef on Reunion Island (Indian Ocean). S.P. C. Bêche-de-mer Information Bulletin 20: 22-25

Conand C (2008) Population status, fisheries and trade of sea cucumbers in Africa and Indian Ocean. In: Toral-Granda V, Lovatelli A, Vasconcellos M (eds) Sea cucumbers. A global review on fishery and trade. FAO Fisheries Technical Paper No. 516, Rome, FAO, pp 153-205

Conand C (2017) Recent trends in the world sea cucumbers fisheries and markets. Revista Biologia Tropical 65 (S1): 1-10

Conand C (2018) Tropical sea cucumber fisheries: changes during the last decade. Marine Pollution Bulletin 133: 590-594

Conand C, Morel C, Mussard R (1997a) A new case of asexual reproduction in holothurians: Fission in *Holothuria leucospilota* populations on Reunion island in the indian ocean. S.P.C. Bêche-de-mer Information Bulletin 9

Conand C, Chabanet P, Cuet P, Letourneur Y (1997b) The carbonate budget of a fringing reef in La Reunion. International Coral Reefs Congres, Panama, 1: 953-958

Conand C, Heeb M, Peyrot-Clausade M, Fontaine MF (1998) Evaluations of bioerosion by two types of the sea urchin *Echinometra mathaei*, on several sites of a fringing reef in La Reunion Island (Indian Ocean) and comparison with other sites. In: Mooi R, Telford M (eds). Echinoderms: San Francisco. A.A. Balkema, Rotterdam: 609-615

Conand C, Uthicke S, Hoareau T (2002) Sexual and asexual reproduction of the holothurian *Stichopus chloronotus* (Echinodermata): a comparison between La Reunion (Indian Ocean) and east Australia (Pacific Ocean). Invertebrate Reproduction Development, 41 (1-3): 235-242

Conand C, Mangion P (2002) Holothurians from La Reunion fringing reefs: diversity, distribution, abundance and population structure. S.P.C. Bêche-de-mer Information Bulletin 17: 27-33

Conand C, Chabanet P, Gravier-Bonnet N (2003) Biodiversité du milieu récifal réunionnais : Echinodermes, Poissons, Hydraires. Rapport Laboratoire Ecomar au Conseil Régional de La Reunion

Conand C, Frouin P (2007) Sea cucumbers in La Reunion. In: Conand C, Muthiga N (eds) Commercial Sea Cucumbers: A Review for the Western Indian Ocean. WIOMSA Book Series No. 5, pp 21-29

Conand C, Muthiga N (2007) Conclusion and recommendations. In: Conand C and Muthiga N (eds) Commercial Sea Cucumbers: A Review for the Western Indian Ocean. WIOMSA Book Series No. 5, pp 57-63

Conand C, Michonneau F, Paulay G, Bruggemann H (2010) Diversity of the holothuroid fauna (Echinodermata) in La Reunion (Western Indian Ocean). Western Indian Ocean Journal Marine Science 9 (2): 145-151

Conand C, Mulochau T, Stohr S, Eléaume M, Chabanet P (2015) Inventory of echinoderms in the Iles Eparses (Europa, Glorieuses, Juan de Nova), Mozambique Channel, France, Acta Oecologica [http://dx.doi.org/10.1016/j.actao.2015.06.007]

Conand C, Ribes Beaudemoulin S, Trentin F, Mulochau T, Boissin E (2016) Oursins, Etoiles de mer & autres échinodermes, Collection Biodiversité de La Reunion. Editions du Cyclone, 168 pp

Emeras J, Falquet MP, Conand C (2004) *Acanthaster planci* on La Reunion reefs (Western Indian Ocean). Reef Encounter 32: 26-27

Eriksson H, Conand C, Lovatelli A, Muthiga N, Purcell SW (2015) Governance structures and sustainability in Indian Ocean sea cucumber fisheries. Marine Policy 56: 16-22

FAO (2013) Report on the FAO Workshop on Sea Cucumber Fisheries: An Ecosystem Approach to Management in the Indian Ocean (SCEAM Indian Ocean) (FAO Fisheries and Aquaculture Report. No. 1038). FAO, Rome.

Gaudron S, Kohler S, Conand C (2008) Reproduction of the sea cucumber *Holothuria leucospilota* in the fringing reef of Reunion Island (Western Indian Ocean): biological and ecological aspects. Invertebrate Reproduction Development 51 (1): 19-31

Guille A, Ribes S (1981) Echinodermes associés aux Scléractiniaires d'un récif frangeant de l'île de La Reunion (océan Indien). Bulletin du Muséum national d'Histoire Naturelle 3 (1): 73-92

Hoareau TB, Conand C (2001) Sexual reproduction of *Stichopus chloronotus*, a fissiparous sea cucumber, on Reunion Island, Indian Ocean. S.P.C. Bêche-de-mer Information Bull. 15: 4-12

Hoareau TB, Boissin E, Paulay G, Bruggemann JH (2013) The Southwestern Indian Ocean as a potential marine evolutionary hotspot: perspectives from comparative phylogeography of reef brittle-stars. Journal of Biogeography 40: 2167-2179

Haszprunar G, Vogler C, Wörheide G (2017) Persistent Gaps of Knowledge for Naming and Distinguishing Multiple Species of Crown-of-Thorns-Seastar in the *Acanthaster planci* Species Complex. Diversity (9) 22 [doi: 10.3390/d9020022]

Jangoux M, Aziz A (1988) Les astéries (Echinodermata) récoltées autour de l'île de la Reunion par le N.O. Marion-Dufresne en 1982. Bulletin du Muséum national d'histoire naturelle. Section A, Zoologie, biologie et écologie animales 4 (10): 631-650

Jaquemet S, Rousset V, Conand C (1999) Asexual reproduction parameters and the influence of fission on a *Holothuria atra* sea cucumber population from a fringing reef on Reunion Island (Indian Ocean). Bêche-de-mer Information Bulletin 11: 12-18

Kohler S, Gaudron S, Conand C (2009) Reproductive biology of *Actinopyga echinites* and other sea cucumbers from Reunion Island (Western Indian Ocean): a contribution for a regional management of the fishery. Western Indian Ocean Journal Marine Science 8 (1): 97-111

Kojadinovic J, Falquet MP, Mangion P, Conand C (2004) Distribution, abundance, and asexual reproduction of *Asterina burtoni* (Asteroidea: Echinodermata) from Reunion reefs (Western Indian Ocean). In: München – Heinzeller, Nebelsick (eds) Echinoderms. Taylor & Francis Group, London, pp 225-230

Lison de Loma T, Harmelin-Vivien M.L, Conand C (1999) Diel feeding rhythm of the sea urchin *Tripneustes gratilla* (L.) on a coral reef at La Reunion, Indian Ocean. In: Candia Carnevali, Bonasoro (eds) Echinoderm Research 1998. Balkema, Rotterdam, pp 87-92

Lison De Loma T, Conand C, Harmelin-Vivien ML, Ballesteros E (2002) Food selectivity of *Tripneustes gratilla* (L.) (Echinodermata: Echinoidea) in oligotrophic and nutrient-enriched coral reefs at La Reunion (Indian Ocean). Bulletin Marine Science 70: 927-938

Mah C. (2018) Asteroid systematics in the 21st century: new questions, phylogeny, taxonomy & natural history. International Echinoderm Conference, Nagoya (plenary lecture, abstract)

Mangion P, Taddei D, Frouin P, Conand C (2004) Feeding rate and impact of sediment reworking by two deposit feeders *Holothuria leucospilota* and *Holothuria atra* on fringing reef (Reunion Island, Indian Ocean). In: München – Heinzeller, Nebelsick (eds). Taylor & Francis Group, London, pp 311-317

Mulochau T, Conand C, Stöhr S, Eleaume M, Chabanet P (2014) First Inventory of Echinodermata at Juan de Nova (Iles Eparses, France) in the Mozambique Channel. Western Indian Ocean Journal Marine Science 13 (1): 23-30

Muthiga N, Conand C (eds) (2014) Sea cucumbers, a Poorly Understood but Important Coastal Resource: A Regional Analysis to Improve Management. WIOMSA Book Series No. 14, 74 pp

Miller AK, Kerr AM, Paulay G, Reich M, Wilson NG, Carvajal JI, Rouse GW (2017) Molecular phylogeny of extant Holothuroidea (Echinodermata). Molecular Phylogenetics and Evolution 111: 110-131

Naim O, Cuet P, Letourneur Y (1997) Experimental shift in benthic community structure. 8th International Coral Reef Symposium 2: 1873-1878

O'Hara TD, Stöhr S, Hugall AF, Thuy B, Martynov A (2018) Morphological diagnoses of higher taxa in Ophiuroidea (Echinodermata) in support of a new classification. European Journal of Taxonomy 416: 1–35 [https://doi.org/10.5852/ejt.2018.416]

O'Loughlin M, Rowe F (2006) A systematic revision of the asterinid genus *Aquilonastra* O'Loughlin, 2004 (Echinodermata: Asteroidea) Memoirs of Museum Victoria 63 (2): 257-287

O'Loughlin M, Mackenzie M (2013) Asterinid seastars from the Mozambique Channel (Echinodermata: Asteroidea: Asterinidae). Zootaxa 3613 (2): 176-180

Ooka S, Komatsu M, Conand C (2010) Sexual reproduction of the small fissiparous seastar *Aquilonastra sp*. (Asteroidea: Asterinidae) in La Reunion Island. In: Harris LG, Boetger SA, Walker CW, Lesser MP (eds) Echinoderms. Durham, Taylor & Francis, London, pp 467-472

Peyrot-Clausade M, Chabanet P, Conand C, Fontaine MF, Letourneur Y, Harmelin-Vivien M (2000) Carbonate budget of two Indo-Pacific reefs: sea-urchin and fish bioerosion in La Reunion and Moorea. Bulletin Marine Science 66 (2): 477-485

Pratchett MS, Ciemon F, Caballes JC, Wilmes J, Matthews S, Melin C, Sweatman H, Nadler L, Brodie J, Thompson C, Hoey J, Bos A, Byrne M, Messmer V, Fortunato S, Chen CC, Buck A, Babcock R, (2017) Thirty Years of Research on Crown-of-Thorns Starfish (1986–2016): Scientific Advances and Emerging Opportunities. Diversity 9, 41; doi:10.3390/d9040041

Purcell SW, Conand C, Uthicke S, Byrne M (2016) Ecological roles of exploited sea cucumbers. Oceanography and Marine Biology: An Annual Review 54: 367-386

Roberts CM, McClean CJ, Veron JEN (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295: 1280-1284

Roux M (1985) Découverte d'un représentant actuel des crinoides pédonculés (Echinodermes) dans l'étage bathyal de l'Ile de La Reunion. Compte Rendus Academie Sciences Paris 301 III, 10: 503-506

Rowe FEW, Massin C (2006) On a new species of *Actinopyga* Bronn, 1860 (Echinodermata, Holothuroidea) from the Indo-West Pacific. Zoosystema 28 (4): 955-961

Rowe FEW, Richmond M (2011) Phylum Echinodermata. In: Richmond (ed) A field guide of the Seashores of Eastern Africa and the Western Indian Ocean Islands. Sida/Wiomsa, 464 pp

Samyn Y, Tallon I (2005) Zoogeography of the shallow-water holothuroids of the western Indian Ocean. Journal Biogeography 32: 1523-1538

Samyn Y, Van den Spiegel D, Massin C (2006) Taxonomie des holothuries des Comores, vol. 1. AbcTaxa, 130 pp

Santos R, Flammang P (2008) Estimation of the attachment strength of the shingle sea urchin, *Colobocentrotus atratus*, and comparison with three sympatric echinoids. Marine Biology [DOI 10.1007/s00227-007-0895-6]

Stöhr S, Conand C, Boissin E (2008) Brittle stars (Echinodermata: Ophiuroidea) from La Reunion and the systematic position of *Ophiocanops* Koehler, 1922. Zoological Journal of the Linnean Society 153: 545–560 [http://dx.doi.org/10.1111/j.1096-3642.2008.00401.x]

Stöhr, S., Boissin, E, Hoareau TB (2013) Taxonomic revision and phylogeny of the *Ophiocoma brevipes* group, with description of a new subgenus (Breviturma) and a new species. European Journal of Taxonomy 68: 1-26 [http://dx.doi.org/10.5852/ejt.2013.68]

Stöhr S, O'Hara T, Thuy B (eds) (2016) World Ophiuroidea database. http://www.marinespecies.org/ ophiuroidea

Uthicke S (2017) Thirty Years of Research on Crown-of-Thorns Starfish (1986–2016): Scientific Advances and Emerging Opportunities Diversity 9, 41 [doi:10.3390/d9040041]

Uthicke S, Conand C, Benzie J (2001) Population genetics of the fissiparous holothurians *Stichopus chloronotus* and *Holothuria atra* (Aspidochirotida): a comparison between Torres Strait and La Reunion. Marine Biology 139: 257-265

Uthicke S, Conand C (2005) Amplified fragment length polymorphism (AFLP) analysis indicates importance of both asexual and sexual reproduction in the fissiparous holothurian *Stichopus chloronotus* (Aspidochirotida) in the Indian and Pacific Ocean. Coral reefs 24 (1): 103-111

Uthicke S, Byrne M, Conand C (2010) Genetic barcoding of commercial Beche-de-Mer species (Echinodermata: Holothuroidea). Molecular Ecology Resources 10: 634-646

Vadon C, Guille A 1984. Les Ophiuridae (Ophiuroidea, Echinodermata) de la campagne MD 32 du 'Marion- Dufresne' autour de l'ile de La Reunion. Bulletin Muséum national d'Histoire Naturelle 4e Series 6: 583-615

Weinberg S, de Ridder C (1998) *Asthenosoma marisrubri* n. sp. (Echinodermata, Echinoidea) from the Red Sea. Beaufortia 48: 27-46

WoRMS Editorial Board (2018) World Register of Marine Species. http://www.marinespecies.org at VLIZ. [doi:10.14284/170]

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Length-weight relationship of selected teleost fishes from Kilifi County, Kenya

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Abstract

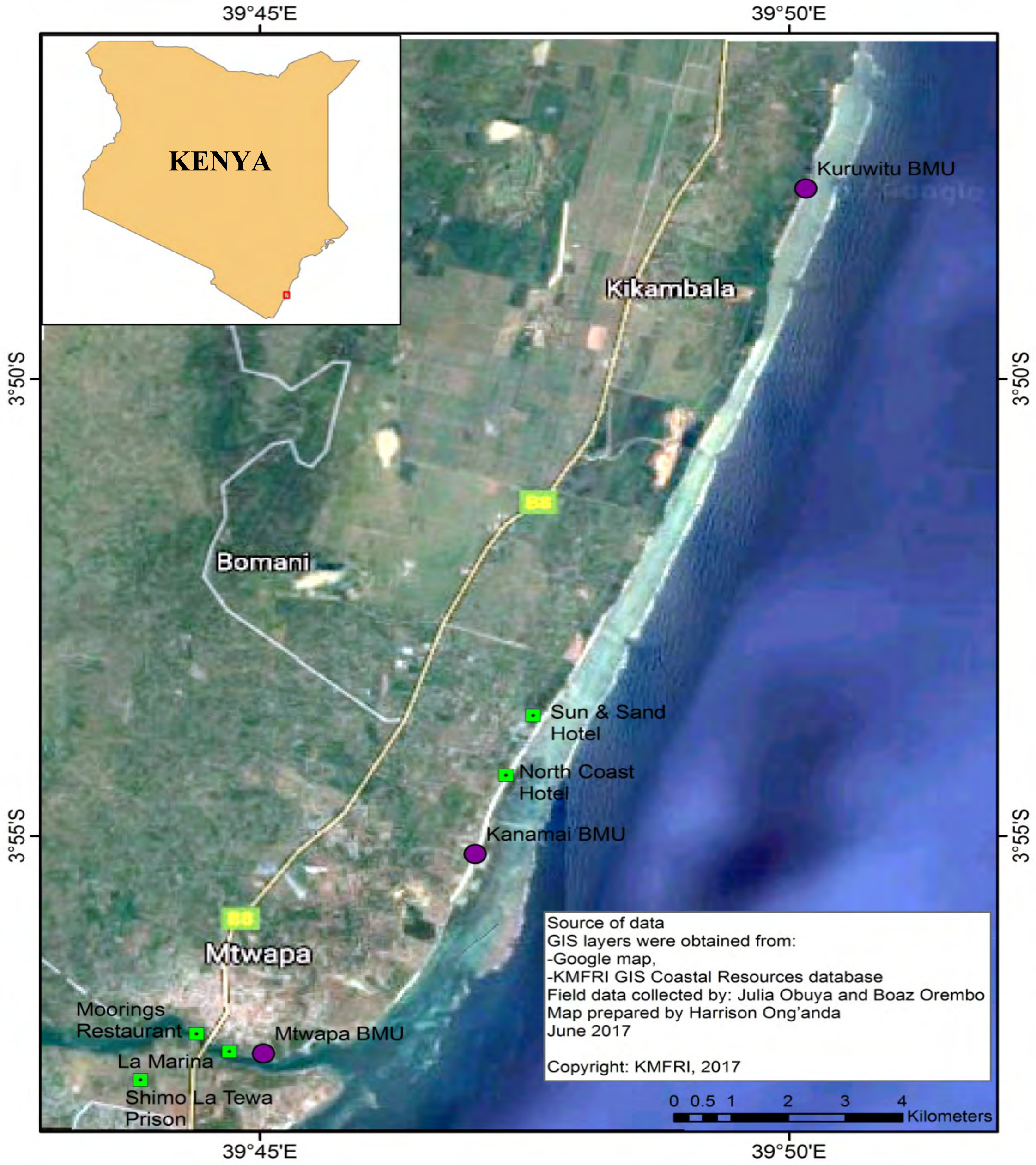
Sustainable exploitation of fishery resources requires knowledge of the population dynamics of the target resources. Length-weight relationship and relative condition parameters were determined for nine teleost fish species, *Calotomus carolinus* (Valenciennes, 1835), *Decapterus macrosoma* (Bleeker, 1851), *Lethrinus nebulosus* (Forsskal, 1775), *Lethrinus harak* (Forsskal, 1775), *Lutjanus fulviflamma* (Forsskal, 1775), *Rastrelliger kanagurta* (Cuvier, 1816), *Sargocenton caudimaculatus* (Ruppel, 1838), *Scomberoides tol* (Cuvier 1832) and *Siganus sutor* (Valenciennes, 1835). The fish were randomly collected from artisanal fishers who operated gears such as gill nets, spearguns and basket traps at three landing sites in Kilifi County between February and April 2017. The linear regression revealed a positive relationship between total length and body weight in all the fish sampled. The t-test calculated on b for most species revealed no significant deviations from the expected cube value of three, except for *L. nebulosus* (t=0.340, $p<0.05$), *R. kanagurta* (t=1.321, $p<0.05$) and *S. sutor* (t=0.961, $p<0.05$). These fish populations are healthy as shown by a relative condition factor above 1 in all species, suggesting that the nutritional requirements are available in the ecosystem, and that the Kilifi coral reefs have thus not been degraded.

Keywords: Length, weight, teleost, Kilifi, condition factor

Introduction

In Kenya, marine fishes are mainly harvested by small scale artisanal fishers operating between the shoreline and the reef (Kimani *et al.,* 2008). The artisanal fishery has been the main cause of decline of populations of reef fishes due to high levels of fishing effort coupled with the use of destructive fishing gears (Mangi and Roberts, 2006). Teleost fishes are the target of a valuable fishery on the Kenyan coast, harvested both for subsistence and commercial purposes. Local fishers have noted a significant decrease in the catch of these fishes. Assessment of the reef fish populations along the coast of Kenya (McClanahan and Abunge, 2014) has shown a consistent and considerable decline in the population density and species richness of most fishes. A shift in the species composition of the landings has occurred, where predatory snappers and groupers once dominated, with opportunistic and lower trophic level species such as rabbitfish becoming more prevalent in the catches (McClanahan and Omukoto, 2011). Fundamental information on the population dynamics of the target species is thus important in the management of the small-scale coastal fishery.

Fish length and weight data are commonly used for analyses in fisheries biology (Mendes *et al.*, 2004). The length-weight relationship (LWR) equation has been extensively used in the study of fish population dynamics for estimating the unknown weights from known lengths in fish stock assessments (Froese and Pauly, 1996). The length and weight data can be used in the estimation of fish growth rates and the overall health of fish stocks (Kohler *et al.,*1996). The relationship between length and weight has also been useful in fishery management by helping in the prediction of potential yields and in determination of size at capture, and for obtaining MSY (maximum sustainable yield), as these management parameters are directly related to the weight of fish (Froese and Pauly, 1996). Considering the LWR of reef associated fishes all over the world,



Source of data
GIS layers were obtained from:
-Google map,
-KMFRI GIS Coastal Resources database
Field data collected by: Julia Obuya and Boaz Orembo
Map prepared by Harrison Ong'anda
June 2017

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Figure 1. Map of Kilifi County in Kenya indicating the sampling sites.

several studies have been carried out. Letourneur *et al.* (1998) reported on the LWR of fishes from lagoons and coral reefs of New Caledonia. In India, LWR and feeding ecology have been investigated in *Siganus canaliculatus* (Park, 1797) from the Gulf of Mannar (Anand and Reddy, 2012; Jayasankar, 1990), and *Lethrinus nebulosus* and *Lethrinus lentjan* (Lacepede, 1802) on the Thoothukudi coast (Vasantharajan *et al.*, 2013).

Studies on the LWR of most reef associated fishes are available in Kenya. Mbaru *et al.* (2010) reported on the LWR of 39 selected reef fishes in Kenyan coastal waters. Kimani *et al.* (2008) studied the morphometric and condition factors of *Siganus stellatus* (Forsskal, 1775), *Siganus canaliculatus* (Park, 1797) and *Siganus sutor* (Valenciennes, 1835). Agembe *et al.* (2010) also studied the catch composition, abundance and LWR of groupers from inshore waters of Kenya. However, most of these studies have been reported from the south coast of Kenya. Kilifi County is home to traditional fishing communities and is an important location for artisanal fishermen on the north coast of Kenya. Only a few estimates of species-specific LWR parameters are available for coastal fishes from this area. The LWR of *Dentex maroccanus* (Valenciennes, 1830) has been the only reported study in Malindi-Ungwana Bay on the north coast of Kenya (Aura *et al.,* 2011). The present study therefore establishes the LWR of nine teleost fishes in Kilifi County, providing additional contribution to the available LWR for the main commercially exploited coral reef fishes in Kenya.

Materials and Methods

Study Area

Kilifi County is located some 60 km north of the city of Mombasa. The area experiences bimodal rainfall consisting of the long rains between April and July and short rains between October and December, generally controlled by the Inter-Tropical Convergence Zone (ITCZ) (McClanahan, 1988). The county is generally warm throughout the year with temperatures ranging between 21 ^{0} C during the coldest months (June and July) and 32 ^{0} C during the hottest months (January and February). Kilifi town is set on Kilifi Creek between Mombasa and Malindi, which is located 52 km to the north. Agriculture, tourism and fishing are the major economic activities in Kilifi. Fishing is widely practiced because of the high demand of fish in Kilifi's hotel industry. Fishing goes on continuously throughout the year within this area. Three sampling sites were selected, Mtwapa, Kanamai and Kuruwitu (Fig. 1). Mtwapa is located within Mtwapa creek, approximately 25 km (3° 57′ S, 39° 45′ E) north of Mombasa. There is a dense mangrove forest of *Rhizophora mucronata* on the extensive mudbanks of the creek. Fresh water input into the creek is from seasonal runoff (Owuor *et al.,* 2017). The creek has also been reported to be eutrophic as a result of direct release of raw sewage from Shimo la Tewa prison (Rodwell *et al.,* 2003). Kanamai is located approximately 10 km (3 °55′ S, 39° 47′ E) north of Mtwapa creek. The area has an extensive sandy beach on the shore. There are however little industrial activities around the area except for few operational hotels. Fishing expeditions are mostly carried out by individuals rather than groups. Kuruwitu sampling site lies approximately 30 km (3° 47′ S, 39° 50′ E) north of Kanamai. The area is dominated by sandy shores with an extensive lagoon. There are, however, few operational hotels along the area. Fishermen in this area are organized within Beach Management Units (BMUs).

Selection of Study sites

The selected study sites occur within the richest fishing grounds in the county, with a high concentration of artisanal fishermen. These study sites had the most operational BMUs under the State Department of Fisheries. The sites have fairly uniform reef lagoon comprising a mixture of sand, seagrass, corals and an outer reef edge that drops into a sand plain at a depth of approximately 10 to 15 m (McClanahan and Abunge, 2014). The lagoon and the immediate reef edge are ecologically similar between sites with regards to habitat and fish compositions, but differ in terms of fish abundance and types of fishing gears employed (McClanahan, 1988).

Fish sampling and Identification

Fish samples were randomly selected from the mixed composition of the landing. The sample size of individual fish species depended on the available mixed catch during the sampling period. Once the fish were landed, the fish families were identified and sorted from the mixed species catch. Taxonomic identification of the fish in the sample was then done up to

Table 1. Summary of LWR in the selected species, sample size (n), total length (TL), total weight (TW) with (±SE), intercept (log a), regression coefficient ‘b’, results of t-test on ‘b’, and coefficient of determination ‘r^2’.

Family	Species	n	TL	TW	Log a	b	t^b	r^2
Carangidae	*D. macrosoma*	52	32.5±0.8	535.2±29.8	-1.144	2.543	2.874	0.843
Carangidae	*S. tol*	49	36.4±0.6	409.1±18.3	-1.246	2.482	5.129	0.926
Holocentridae	*S. caumadiculatus*	48	20.8±0.3	124.5±5.9	1.455	2.680	2.119	0.868
Lethrinidae	*L. nebulosus*	50	22.7±0.5	332.71±21.7	-1.525	2.957	0.341	0.920
Lethrinidae	*L. harak*	53	30.5±0.5	317.3±13.8	-1.503	2.687	2.566	0.910
Lutjanidae	*L. fulviflamma*	50	29.7±0.7	349.2±20.4	-0.936	2.347	4.503	0.845
Scaridae	*C. carolinus*	51	24.4±0.7	303.6±17.5	-0.613	2.214	9.704	0.940
Scombridae	*R. kanagurta*	55	25.1±0.3	296.8±11.9	-2.091	3.248	1.318	0.860
Siganidae	*S. sutor*	49	30.0±0.6	381.6±25.9	-1.619	2.820	0.957	0.825

species level with the help of a standard reference book (Anam and Mostarda, 2012).

Length-Weight Relationship

The total length (TL) from tip of snout to tip of caudal fin was measured to 0.1 cm precision using a tape measure, while wet body weight (BW) was measured using a portable electronic weighing scale (WeiHeng 40/10, Japan) to 0.1 g precision.

Data analysis

Data was analyzed using SPSS statistical software. The data generated from the measured parameters were expressed using descriptive statistics. The statistical relationship between the length and weight of fishes was established as per the parabolic equation $TW = aTL^b$ (Froese, 2006). Where: TW = Total Wet body weight of fish in grams; TL = Total length of fish in centimeters; a = Y intercept; and b = slope of the line, respectively. The length-weight relationship was obtained by logarithmic transformation of ($TW = aTL^b$) to provide a linear association between the variables. The least squares method on a linear regression model was used for expression: $\log W = \log (a) + b \log (L)$ (Le Cren, 1951). A plot of log (L) against log (W) for the species was used to estimate the intercept and slope variables, a and b respectively, of the equation (Hayes *et al.*, 1995). The exponent b of the LWR for the species was tested for significant deviation from the isometric value of b = 3 following (Froese, 2006). Relative condition (k_n) factor was calculated following Le Cren's (1951) formula, $K_n = W/\hat{}W$. W is the observed weight and $\hat{}W$ is the weight calculated from the length-weight relationship $\hat{}W = aL^{3-b}$. Pooled totals of length-weight data for individual species obtained during the study was used. All statistical tests were conducted at a significance level of 95% ($\alpha = 0.05$).

Results

Length-Weight Relationship

A total of 457 fishes from seven families, eight genera and nine species were collected for length-weight analysis (Table 1). These species (Fig. 2) were selected because they dominated the landings. The LWR of the fish species are shown in Figs. 3-11. The sample sizes ranged from 48 individuals for *S. caudimaculatus*,

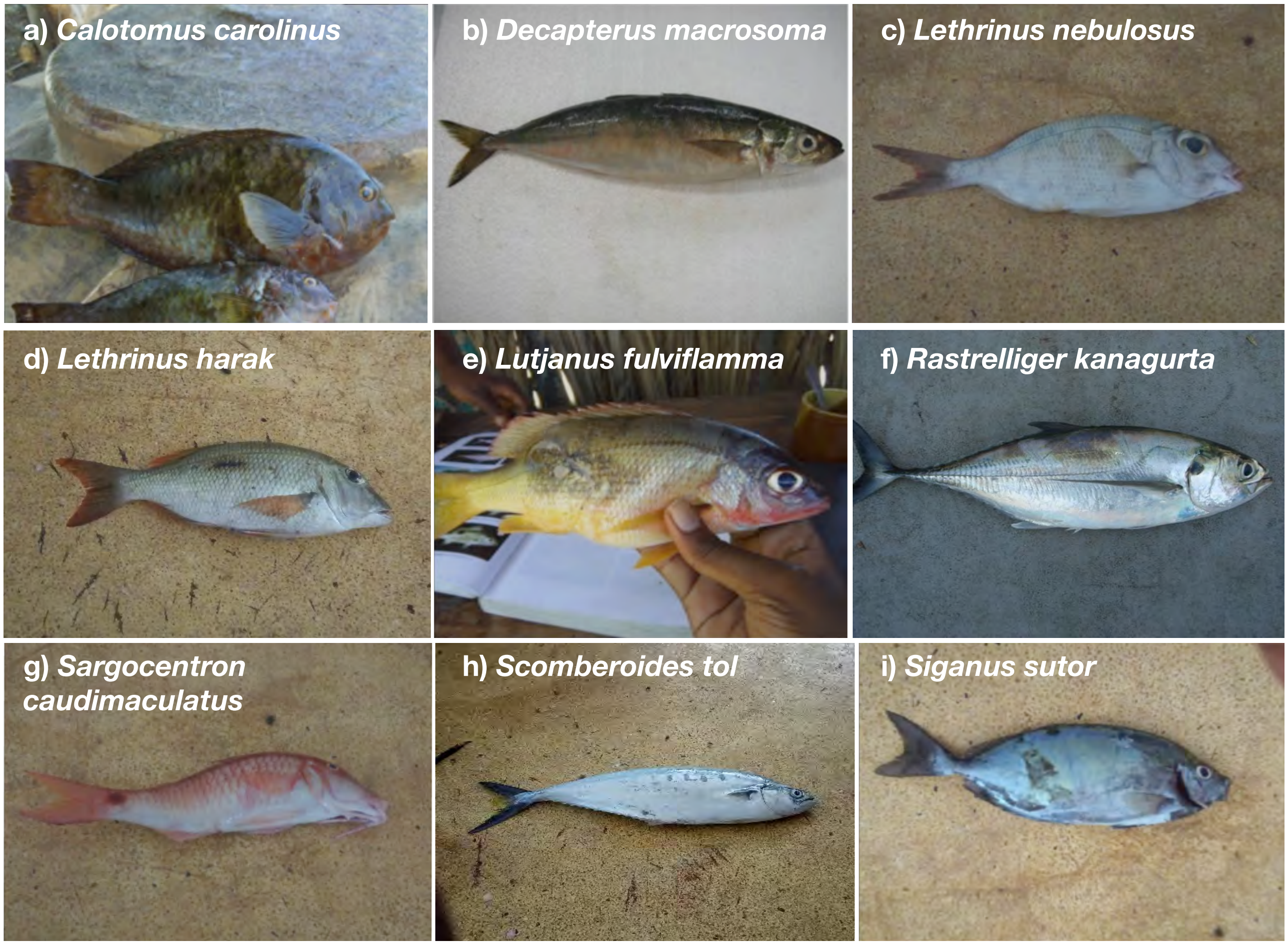

Figure 2. Selected teleost fishes from Kilifi sampling sites (Photo credits: Julia, 2017).

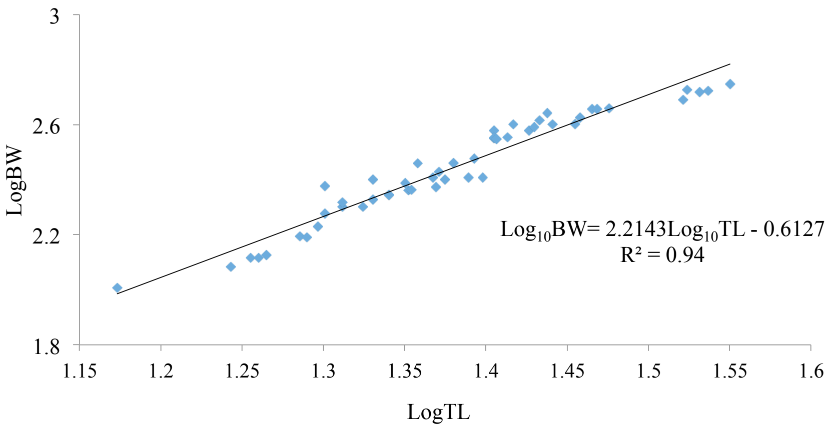

Figure 3. The Length-Weight relationship in *C. carolinus*.

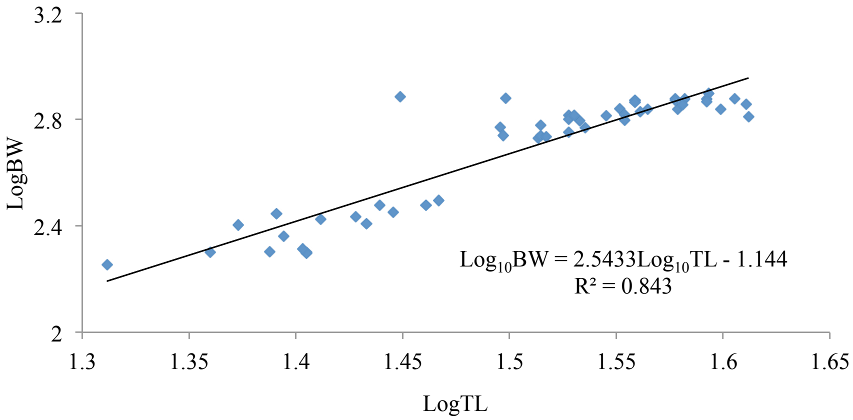

Figure 4. Length-Weight relationship in *D. macrosoma*.

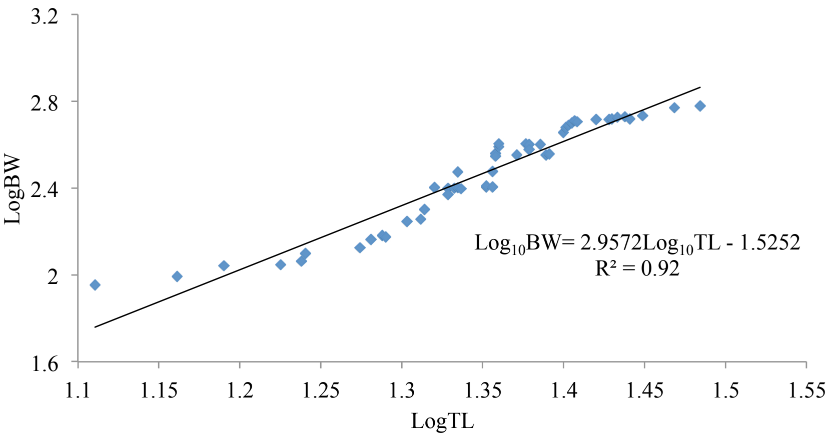

Figure 5. Length-Weight relationship in *L. nebulosus.*

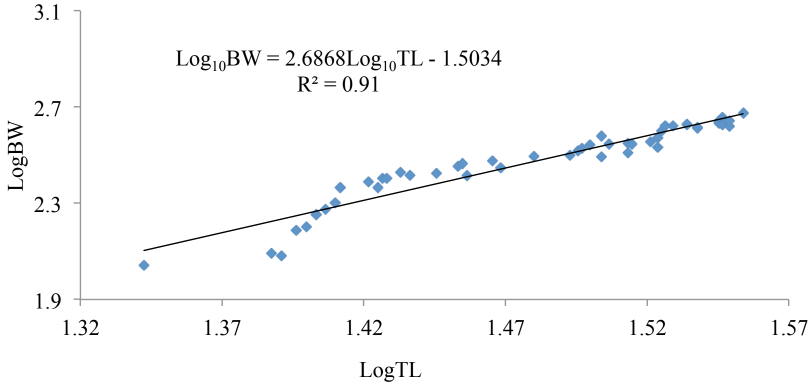

Figure 6. Length-Weight relationship in *L. harak*.

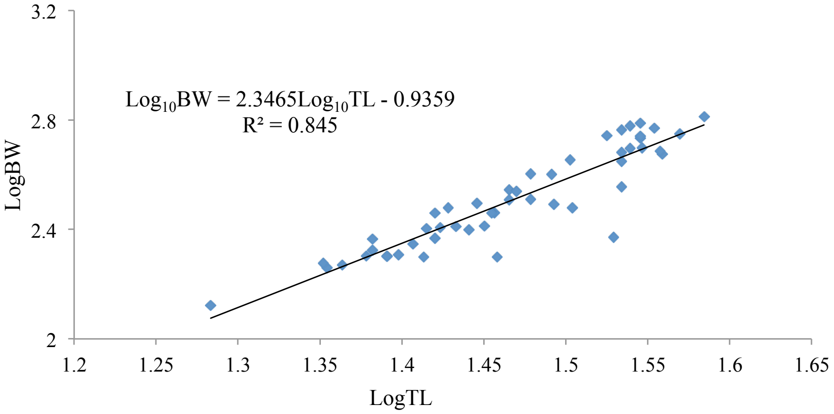

Figure 7. Length-Weight relationship in *L. fulviflamma*.

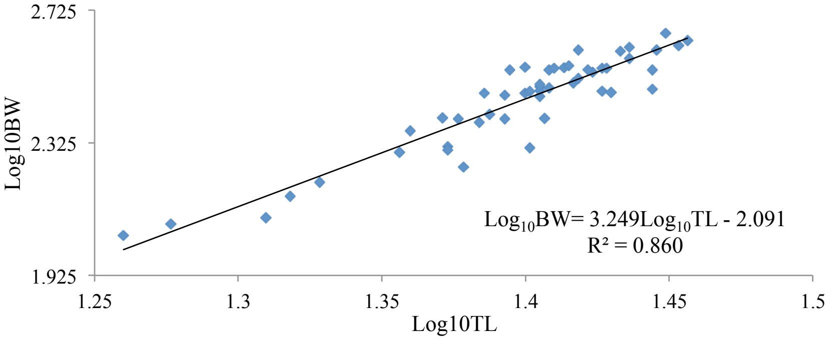

Figure 8. Length-Weight relationship in *R. kanagurta*.

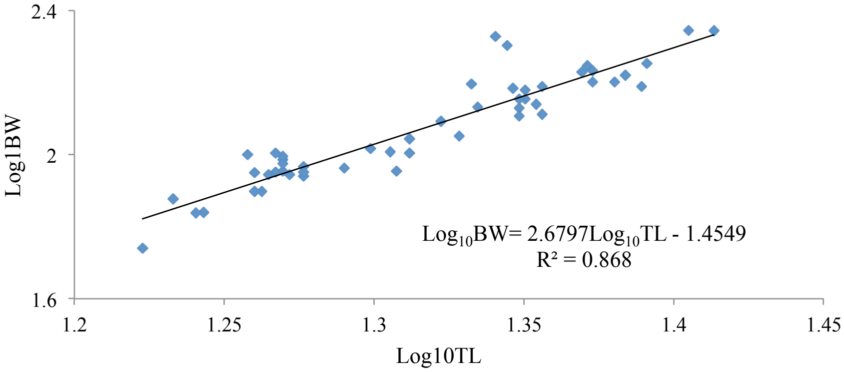

Figure 9. Length-Weight relationship in *S. caudimaculatus*.

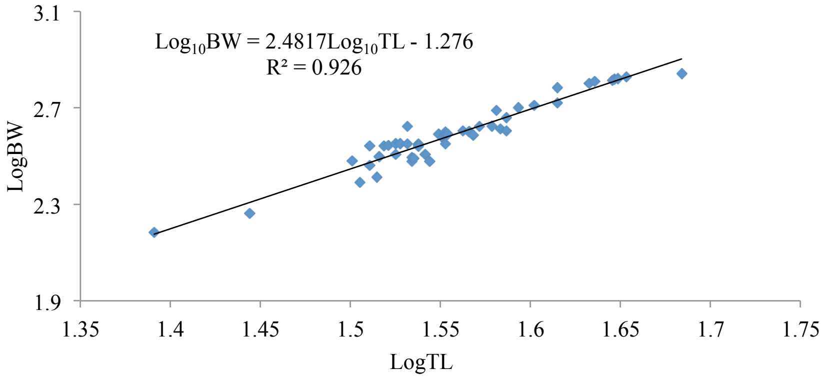

Figure 10. Length-Weight relationship in *S. tol*.

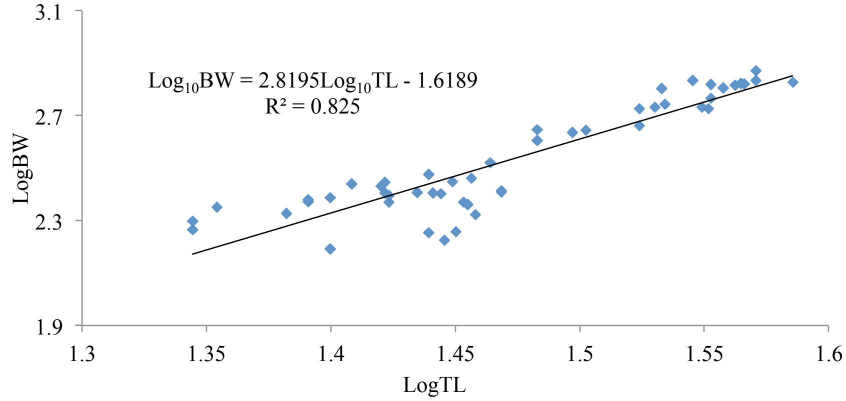

Figure 11. Length-Weight relationship in *S. sutor*.

to 55 for *R. kanagurta*. The coefficient of determination (r^2) values ranged from 0.825 for *S. sutor* to 0.940 for *C. carolinus*. The exponent 'b' value ranged from 2.214 for *C. carolinus* to 3.249 for *R. kanagurta*. T-tests revealed no significant deviation from the expected cube value of 3 for most species (Table 1). Significant differences were noted for *L.nebulosus*, *R. kanagurta* and *S. sutor*.

Condition Factor

The overall relative condition factor (K_n) for the nine species sampled is presented in Table 2.

Table 2. Mean relative condition factor (K_n) for the selected species.

Species	Overall relative condition factor (Mean±SE)
Calotomus carolinus	1.006±0.053
Decapterus Macrosoma	1.021±0.089
Lethrinus harak	1.006 ±0.032
Lethrinus nebulosus	1.012±0.043
Lutjanus Fulviflamma	1.013±0.076
Rastrelliger kanagurta	1.008±0.053
Sargocentron caudimaculatus	1.008±0.009
Scomberoides tol	1.004±0.086
Siganus sutor	1.019±0.071

Discussion

Length-Weight Relationship

Various authors have studied the LWR of most fish and fishery resources in different regions worldwide. Varying values of b for various fishes have been reported. Allen (1938) indicated that for an ideal fish exhibiting isometric growth, the b value should be 3. Beverton and Holt (1957) also pointed out that the cube law for length and weight relationship prevailed and proposed that the b value is close to 3.0. The cube law suggests constancy of density and form in an ideal fish. However, as fish grow in length, they change in form and shape which causes a deviation from the cube law proposed for the ideal fish. Le Cren (1951) suggested that these deviations could be ascribed to the physiological condition of the fish, environmental parameters, sex, taxonomic differences or reproductive activities. Ricker (1973) reported that the b value of a reasonable fish species is close to this ideal value of 3 although the cube law does not usually hold true for most fishes. The b value may change due to changes in body proportions during the life of a fish, maturity and geographical localities (Ricker, 1973). Carlander (1982) and Froese (2006) later mentioned that the value of b is usually close to 3.0 but could range between 2.5 and 3.5 due to the variations listed earlier.

The present study on LWR conducted on the nine demersal fishes showed that the estimates of b value for the species fell within the expected range 2.5 < b > 3.5 for fishes as suggested by Carlander (1982) and Froese (2006). The b values for most of the species were significantly lower than 3.0 suggesting that these fishes are lighter in relation to their individual lengths. There were no significant differences in the LWR of these species indicating homogeneity in their growth pattern. Significant deviation of b from the cube value was noticed for *L. nebulosus*, *R. kanagurta* and *S. sutor*. *L. nebulous* had a b value which was very close to 3.0 indicating isometric growth, while *R. kanagurta* had a b value significantly higher than 3.0 for isometric growth, indicating a tendency towards slightly positive allometric growth. The observed b values for *L. nebulosus*, *R. kanagurta* and *S. sutor* were close to 3 suggesting that these fishes are neither heavier nor lighter in relation to their individual lengths. However, the observed b values could not be compared for consistency since the investigated fishes belonged to different species having differing rates of metabolism.

In the LWR of fish, the exponent b shows a normal distribution on both sides of the cubic value with little variation (Froese, 2006). These variations might be attributed to the impact of water quality or availability of food on the growth of fish (Mommsen, 1998). The b values revealed by Mbaru *et al.* (2010) for *D. macrosoma* (3.930), *L. nebulosus* (3.024), *L. harak* (3.082), *L. fulviflamma* (3.987) and *S. sutor* (3.290) are slightly higher compared to the present findings of LWR of similar species in Kenya. Vasantharajan *et al.* (2014) and Kimani *et al.* (2008) however, reported almost similar b values for *L. nebulosus* (2.964) and *S. sutor* (2.716) in India and the south coast of Kenya, respectively. Variation in LWR variables may represent differences over time (Sparre *et al.*, 1989). Nevertheless, the observed deviations in this current comparison could be due to a smaller sample size (n < 100) compared to the many specimens (n > 100) from which the LWRs of the earlier studies were derived. The deviations could also be due to the disparities in sampling period and the size range of catches in this specific area during the sampling period (Kimmerer *et al.,* 2005; Froese, 2006). Other factors such as fishing seasons and fishing gears could have also resulted in the observed differences.

LWR is not constant for fishes from various geographical regions and the b values may be influenced by environmental factors such as salinity, availability of food and water temperature (Kimmerer *et al.,* 2005). In the Caspian Sea, Daliri *et al.* (2012), and India, Abdurahiman *et al.* (2004) reported b value for *L. nebulosus* (2.683) and *S. tol* (2.937), respectively. These results differ from the present findings of b values for the two species. Ongkers *et al.* (2017) reported b values for *D. macrosoma* ranging from 2.976 to 4.108 in Ambon, Indonesia, but this study reports a lower value of 2.543 for the species. The variations observed in the current study could be ascribed to the ecological variations of the geographical localities and differing habitat conditions (Froese, 2006).

Biological factors such as sex, health, and morphological differences can also result in the observed differences (Ricker, 1973; Froese, 2006). Letourneur *et al.* (1998) reported the b values for *Scomberoides lysan* (Forsskal, 1775), a species of the same genus as *S. tol*, to be 2.896 and 2.685 in New Caledonia and South Africa, respectively. These values are higher than the calculated b value for *S. tol* in the current study. Siganid populations in other parts of the world have also indicated variations in the observed b values. Al-marzouqi *et al.* (2009) reported the b values of male and female *Siganus canaliculatus* (Park, 1797), which belongs to the same genus as *S. sutor* on the Arabian Sea coast of Oman, as

2.674 and 2.805, respectively, which is similar to the present findings of b value for the species. These similarities could be due to the fact that the two localities fall within the Western Indian Ocean eco-region.

The b values reported by Amal *et al.* (2015), Jayabalan *et al*. (2014), Abdussamad *et al.* (2006), Mehanna (2001), and Torres (1991) for *R. kanagurta* in Pakistan, the Sohar coast of Oman, India, the Red sea, and South Africa, respectively, concur with the b value recorded for the same species. This indicates that the species is stable in a range of environmental conditions. However, comparison of the results of this study show that two species, *C. carolinus* and *S. caudimaculatus*, lack existing statistical records on LWR in FishBase or any other source for Kenya, thus this study is the first to document this parameter.

Condition factor

Le Cren (1951) suggested the calculation of relative condition factor (Kn) based on LWR in order to eliminate the variation caused by length and other factors such as maturity, age, sex, sampling methods and feeding intensity of fish. Kn in fishes reflects the physiological state of a fish in relation to its welfare (Lambert and Dutil, 1997). Kn also gives information when comparing two populations living in certain feeding density, climate, and other conditions (Lambert and Dutil, 1997). Slight deviations were noticed in the monthly relative conditions of the species. These deviations could be due to the changing physical conditions and nutritional requirements of the fish species which were not considered in the present study. Kimani *et al*. (2008) reported a condition factor of 1 for siganid populations on the south coast Kenya. Aura *et al*. (2011) and Mbaru *et al*. (2010) investigated the Kn of selected reef species along the Kenyan coast reporting a Kn of close to 1. The overall Kn of the nine species in the current study conforms to the earlier studies indicating a Kn of greater than 1 and suggesting that the fish species were healthy.

Fish populations in relatively warm and eutrophic locations are in better conditions due to the prevailing favorable feeding and physiological conditions (Jakob *et al*., 1996; Lambert and Dutil, 1999). The Kenyan coastal climate regime is divided into two distinct monsoon seasons; the warm north east monsoon and cool south east monsoon (McClanahan, 1988). Fish were sampled during the dry north east monsoon which is usually a period of warm and calm waters. The north east monsoon winds bring with it the Somalian stream current that causes upwelling in the upper reaches of the north coast banks of Kenya. This current counteracts with the Equatorial Counter Current creating a turbulence which enhances primary production, subsequently creating a fertile fishing ground (McClanahan, 1988). This could in part explain why the conditions of the fish species studied are relatively high in Kilifi County, suggesting that the coastal water of Kilifi County is suitable for most fish species.

Conclusion

This study has provided additional information on the LWR of nine commercially important teleost fishes in Kilifi County that will also allow for future comparisons between populations of the same species. Data generated will form a baseline tool for enhanced fisheries management and utilization of species that are of commercial importance to improve sources of livelihood to the local communities. However, more extensive research needs to be undertaken which would involve the standardization of the sampling seasons and sample sizes, measurement of environmental physico-chemical parameters, as well as obtaining a better understanding of the biology of the species involved, before additional inferences can be made.

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References

Abdurahiman K, Nayak T, Zacharia P, Mohamed K (2004) Length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India. NAGA, World Fish Centre Quarterly 27 (1&2): 9-14

Abdussamad M, Mohamad Kasim H, Achayya P (2006) Fishery and population characteristics of Indian mackerel, *Rastrelliger kanagurta* (Cuvier). Indian Journal of Fisheries 53 (1): 77-83

Agembe S, Mlewa C, Kaunda-Arara B (2010) Catch composition, abundance and length-weight relationships of groupers (Pisces: *Serranidae*) from inshore waters of Kenya. Western Indian Ocean Journal of Marine Science 9 (1): 91-102

Allen K R (1938) Some observations on the biology of the trout (Salmo trutta) in Windermere. The Journal of Animal Ecology 1: 333-349.

Al-Marzouqi A, Al-Nahdi A, Jayabalan N, Al-Habsi S (2009) Stomach contents and length-weight relationship of the white-spotted rabbitfish *Siganus canaliculatus* (Park, 1797) from the Arabian Sea coast of Oman. Journal of Marine Biological Association of India 51: 211-216

Amal A, Sabrah M, El-Ganainy A, EL–Sayed A (2015) Population structure of Indian mackerel, *Rastrelliger kanagurta* (Cuvier, 1816), from the Suez Bay, Gulf of Suez, Egypt. International Journal of Fisheries and Aquatic Studies 3 (1): 68-74

Anam R, Mostarda E (2012). FAO species identification field guide to the living marine resources of Kenya. FAO, Rome, 376 pp

Anand A, Reddy P, (2012) Length-weight relationship of the whitespotted rabbitfish *Siganus canaliculatus* (Park, 1797) from Gulf of Mannar, South India. Journal of the Marine Biological Association of India 54 (1): 91-94

Aura C, Munga C, Kimani E, Manyala J, Musa S (2011) Length-Weight Relationships for Nine Deep Sea Fish Species off the Kenyan Coast. Pan-American Journal of Aquatic Sciences 6 (2): 188-192

Beverton R, Holt S (1957) On the dynamics of exploited fish populations. Fisheries Investigation Series 2, volume 19, UK Ministry of Agriculture. Fisheries, and Food, London, UK.

Carlander KD (1982) Standard intercepts for calculating lengths from scale measurements for some centrarchid and percid fishes. Transactions of the American Fisheries Society 111 (3): 332-336

Daliri M (2012) Length-weight and length-length relationships, Relative condition factor and Fultons condition factor of Five Cyprinid species in Anzali wetland, southwest of the Caspian Sea. Caspian Journal of Environmental Sciences 10 (1): 25-31

Froese R (2006) Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations: Journal of Applied Ichthyology 22: 241-253

Froese R, Pauly D (1996) Concepts, design and data sources: International Center for Living Aquatic Resources Management. FishBase 96

Hayes D, Brodziak J, O'Gorman J (1995) Efficiency and bias of estimators and sampling designs for determining length-weight relationships of fish. Canadian Journal of Fisheries and Aquatic Sciences 52 (1): 84-92

Jakob E, Marshall S, Uetz G (1996) Estimating fitness: a comparison of body condition indices. Oikos 77 (1): 61-67

Jayabalan N, Zaki S, Al-Kiyumi F, Al-Kharusi L, Al-Habsi S (2014) Age, growth and stock assessment of the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1817) along the Sohar coast of Oman. Indian Journal of Fisheries 61 (1): 1-6

Jayasankar P (1990) Some aspects of biology of the white-spotted spine-foot, *Siganus canaliculatus* (Park, 1797) from the Gulf of Mannar. Indian Journal of Fisheries 37: 9-14

Kimani E, Ohtomi J, Kulundu N, Wambiji N, Fulanda B, Hossain M (2008) Morphometric Relationship and Condition Factor of *Siganus stellatus*, *S. canaliculatus* and *S. sutor* (Pisces: Siganidae) from the Western Indian Ocean Waters. South Pacific Studies 29 (1): 1-15

Kimmerer W, Avent S, Bollens S, Feyrer F, Grimaldo L, Moyle P, Visintainer T (2005) Variability in length–weight relationships used to estimate biomass of estuarine fish from survey data. Transactions of the American Fisheries Society 134 (2): 481-495

Kohler N, Casey J, Turner P (1996) Length-length and length-weight relationships for 13 shark species from the western North Atlantic. Fishery Bulletin of the National Oceanic and Atmospheric Administration 93 (2): 1-22

Lambert Y, Dutil J (1997) Condition and energy reserves of Atlantic cod (*Gadus morhua*) during the collapse of the northern Gulf of St. Lawrence stock. Canadian Journal of Fisheries and Aquatic Sciences 54 (10): 2388-2400

Le Cren ED (1951) The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20: 201-219

Letourneur Y (1998) Length-weight relationship of some marine fish species in Reunion Island, Indian Ocean. NAGA, the ICLARM Quarterly 21 (4): 37-39

Letourneur Y, Kulbicki M, Labrosse P (1998) Length-weight relationship of fishes from coral reefs and lagoons of New Caledonia. An update: NAGA, the ICLARM Quarterly 21 (4): 39-46

Mangi S, Roberts C (2006) Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. Marine Pollution Bulletin 52 (12): 1646-1660

Mbaru E, Mlewa C, Kimani E (2010) Length–weight relationship of 39 selected reef fishes in the Kenyan coastal artisanal fishery. Fisheries Research 106 (3): 567-569

McClanahan T (1988) Seasonality in East Africa's coastal waters. Marine Ecology Progress Series: 191-199

McClanahan T, Omukoto J (2011). Comparison of modern and historical fish catches (AD 750-1400) to inform goals for marine protected areas and sustainable fisheries. Conservation Biology 25 (5): 945-955

McClanahan T, Abunge C (2014) Catch rates and income are associated with fisheries management restrictions and not an environmental disturbance, in a heavily exploited tropical fishery. Marine Ecology Progress Series 513: 201-210

Mehanna S (2001) Dynamics and management of the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1816) in the Gulf of Suez, Egypt. Journal of Aquatic Biology and Fisheries 5 (3): 179-19

Mendes B, Fonseca P, Campos A (2004) Weight–length relationships for 46 fish species of the Portuguese west coast. Journal of Applied Ichthyology 20 (5): 355-361

Mommsen T (1998) Paradigm of growth in fishes. The Physiology of Fishes. CRC Press, New York, pp 65-98

Ongkers O, Pattiasina B, Tetelepta J, Natan Y, Pattikawa J (2014) Some biological aspects of painted spiny lobster (*Panulirus versicolor*) in Latuhalat waters, Ambon Island, Indonesia. International Journal of the Bioflux Society 7 (6): 469-474

Owuor M, Icely J, Newton A, Nyunja J, Otieno P, Tuda A, Oduor N (2017) Mapping of ecosystem services flow in Mida Creek, Kenya. Ocean & Coastal Management 140: 11-21

Ricker W (1973) Linear regressions in fishery research: Journal of the Fisheries Board of Canada 30 (3): 409-434

Rodwell L, Barbier E, Roberts C, McClanahan T (2003) The importance of habitat quality for marine reserve fishery linkages. Canadian Journal of Fisheries and Aquatic Sciences 60 (2): 171-181

Sparre P, Ursin E, Venema S (1989) Introduction to tropical fish stock assessment. Part 1. Manual. In: FAO Fisheries Technical Paper No. 306

Torres J, Francisco R, Pauly D (1991) Tabular data on marine fishes from Southern Africa, Part II: Growth parameters. Fishbyte 9: 37-38

Vasantharajan M, Jawahar P, Sundaramoorthy B, Venkatasamy M (2014) Length-weight relationship of *Lethrinus lentjan* (Lacepede, 1802) and *Lethrinus nebulosus* (Forsskal, 1775) exploited in Thoothukudi coast, Tamil Nadu. Indian Journal of Veterinary and Animal Science Research 43: 14-18

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