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SHORT COMMUNICATION

Rapid Visual Assessment of Fish Communities on Selected Reefs in the Bazaruto Archipelago

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Keywords: Bazaruto Archipelago, Mozambique, ichthyofauna, fish surveys, underwater visual census, coral reefs.

Abstract— Rapid visual censuses were conducted of fish on eight coral reefs in the Bazaruto Archipelago, Mozambique, in 2007. SCUBA and snorkelling were used for the censuses in depths between 1-20 m, yielding an inventory of 249 fish species belonging to 50 families. This is intended to serve as a baseline for more detailed studies and monitoring programmes in the future. Although fewer species were recorded relative to other studies conducted in the Western Indian Ocean, the trophic structure on Bazaruto's reefs proved typical for the region, indicating a relative measure of reef health. However, other regional studies were not directly comparable, differing in habitat, duration of sampling effort and methodology. This highlighted the need for a long-term monitoring programme specifically adapted for the Bazaruto reef types to provide a basis for their sound management and conservation.

INTRODUCTION

The Bazaruto Archipelago consists of five islands and is located approximately 20 km off the coast of Mozambique in the Western Indian Ocean (WIO). The seas around the archipelago are rich in marine life and provide an important source of protein to the local community

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(Everett *et al.,* 2008; Reina, 1998). The ecological importance of the archipelago first received attention in 1971 with three of the islands, Benguera, Magaruque and Bangue, receiving national park status (area of protection ~600 km^2); Bazaruto and Santa Carolina were only designated as 'special surveillance zones' (Reina, 1998). After many years, the Bazaruto Archipelago National Park (BANP) was proclaimed in 2001, protecting all five islands. The BANP was extended in 2003 to include the Cabo de São Sebastião peninsula in the south and now covers 1430 km^2. Mozambique's Ministry of Tourism is responsible for management of the BANP.

The coral and rocky reefs in the archipelago provide habitat for a wealth of biodiversity, making it a popular tourist destination (Schleyer & Celliers 2005). Visiting SCUBA divers and recreational anglers bring in valuable revenue to the area and, although fishing is allowed in the BANP, it is regulated by means of permits and no-take zones. All recreational fishing requires a permit and is mostly boat-based, emanating from a number of resorts scattered through the islands. A number of seasonal fishing competitions are hosted by the various resorts, bringing in foreign anglers.

The artisanal fishery is the main economic activity for more than 70% of the local population (Everett *et al.,* 2008). Artisanal fishermen harvest fish using dhows, pirogues, approved beach seines, gamboa traps and spearguns. Mozambican citizens living outside the BANP are only allowed to use handlines inside the park and are allowed to use beach-seines in a small area south of Magaruque. Gill-netting is prohibited and no industrial or semi-industrial fishing operations are allowed in the BANP. The no-take zones are Two-mile Reef, Lighthouse Reef, Santa Carolina and small rocky outcrops on the inside and outside of Bazaruto Island (Fig. 1). However, only Two-mile Reef, Lighthouse Reef and Santa Carolina enjoy strong compliance. There are no seasonal restrictions on fishing in the BANP and recreational SCUBA diving and snorkelling is allowed in the no-take zones. A new management plan is being developed for the Park but, at the time of writing, had not yet been implemented.

The livelihoods of the local communities depend, to a great extent, on marine and coastal resources (Everett *et al.,* 2008). An increasing population characterises many coastal communities in the WIO, placing pressure on such resources (Lindén *et al.,* 2002). Effective management is thus required, the success of which depends on monitoring programmes (Obura *et al.,* 2002). These have been seen as a priority in the WIO region since the 1998 mass coral bleaching event (Lindén *et al.,* 2002). Monitoring of a resource depends on a thorough knowledge of the biodiversity of an area. Species inventories comprise

a fundamental baseline in this regard, providing a foundation for an understanding of ecological processes and the effects of biodiversity loss on ecosystem function (Bellwood & Hughes 2001; Gillibrand *et al.,* 2007). Baseline fish community data are sparse for the WIO region but those published include fish inventories for the Glorieuses Islands (Durville *et al.,* 2003), Mayotte (Chabanet, 2002), Andavadoaka (Gillibrand *et al.,* 2007), Juan De Nova (Chabanet & Durville 2005), Tuléar (Harmelin-Vivien, 1979) Geyser and Zéléé (Chabanet *et al.,* 2002), Réunion (Chabanet, 1994), Sodwana Bay (Chater *et al.,* 1993; 1995) and Bassas da India (van der Elst & Chater 2001).

Pereira (2000) prepared a general checklist of reef-associated fishes for Mozambique, Benayahu & Schleyer (1996) and Schleyer & Celliers (2005) compiled coral inventories for the Bazaruto reefs, Motta *et al.,* (2002) and Rodrigues *et al.,* (2000) quantified fish communities at two sites off Bazaruto and van der Elst & Afonso (2008) compiled a fish inventory based on work undertaken at Bazaruto in the late 1980s. However, there appears to have been no further ichthyofaunal research in the Bazaruto Archipelago. This paper, therefore, presents a recent and more comprehensive inventory of the fish community as a precursor to further ecological studies on the Bazaruto reefs and highlights the need for long-term monitoring.

MATERIALS AND METHODS

Study Area

The Bazaruto Archipelago is a chain of four islands, Bazaruto, Benguera, Magaruque and Bangue, with a fifth island, Santa Carolina, lying on the inside of the island chain (Fig. 1). The reefs around the archipelago are diverse and include rocky patch reefs, rocky massifs, fringing and barrier coral reefs and deeply submerged coral reefs (Schleyer & Maggs 2008). The fish community assessment was undertaken on all these reef types in depths from 1-20 m. A range of reef habitats within these reef types was sampled with varying coral cover and topographic complexity.

Twelve-mile Reef is a submerged sandstone coral reef roughly twelve nautical miles (18 km) north of Bazaruto's northern point in the open sea. It is open to fishing and SCUBA diving but is relatively inaccessible for artisanal fisherman using traditional pirogues and dhows. However, recreational fishers and SCUBA divers, using large boats with outboard engines, are able to access this reef. Relative to the other reefs sampled in this study, Twelve-mile Reef lies furthest from the waters enclosed between the islands and the mainland. The reef was sampled at depths between 15-20 m.

Tubarão, Garoupa and Kingfish Reefs are sedimented rocky patch reefs which are open to fishing and

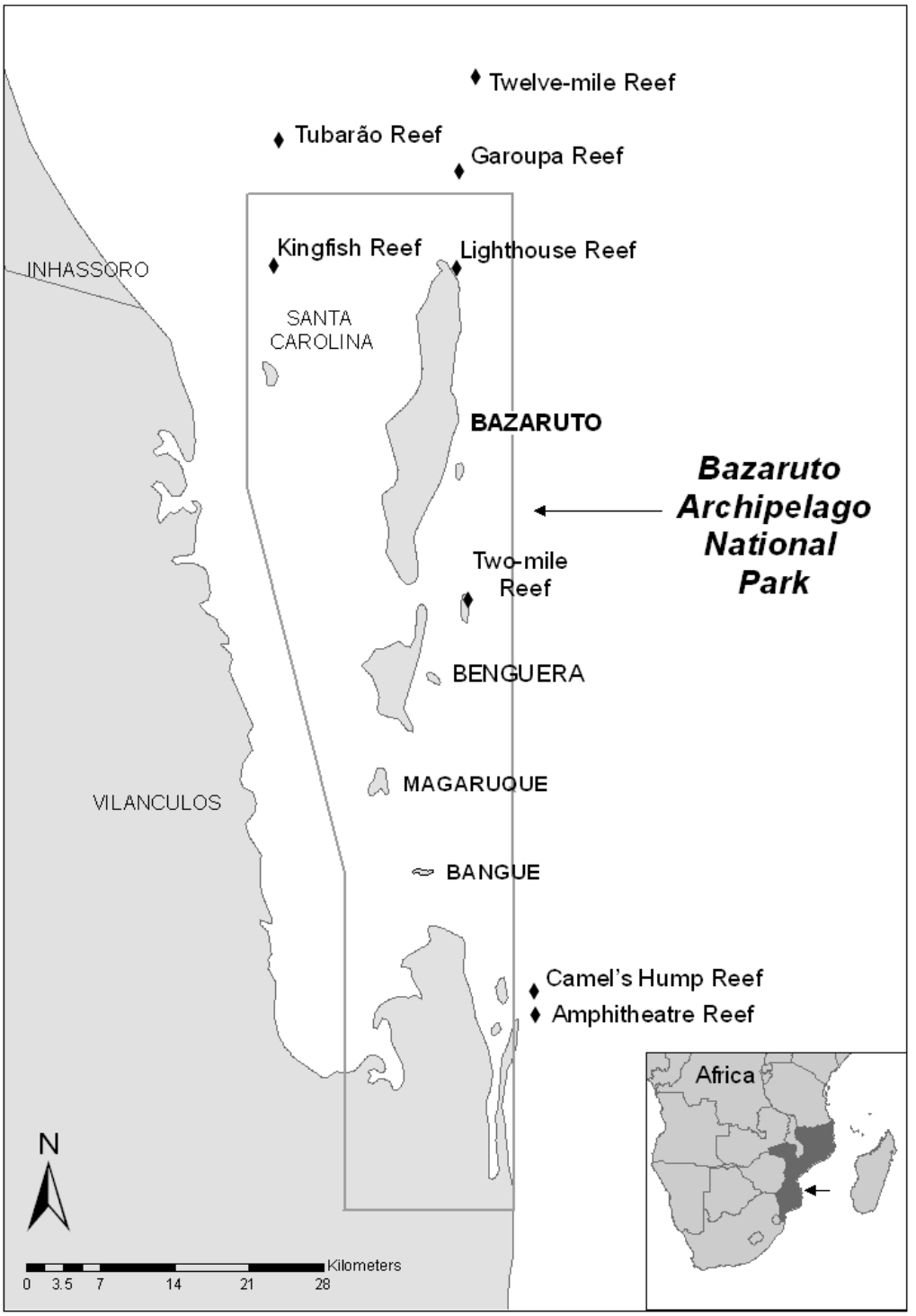

Fig. 1. Map of the Bazaruto Archipelago, Mozambique. Study sites are indicated by (♦).

SCUBA diving. Garoupa lies nine km north of Bazaruto and was sampled at 16-20 m. Tubarão lies 19 km north-east of Inhassoro and was sampled at 13-18 m. Kingfish Reef is 13.5 km east of Inhassoro and was sampled at 6-11 m. High turbidity is common on these reefs.

Lighthouse Reef is a fringing coral reef located on the north-eastern tip of Bazaruto. It is a no-take zone and is closed to fishing (including artisanal fishing) but open to SCUBA diving and snorkelling. Only the inner lagoon was sampled and the depth ranged between 1-3 m.

Two-mile Reef is a barrier coral reef which lies four kilometres out to sea between Bazaruto and Benguera Islands. This reef is also a no-take zone being closed to fishing (including artisanal fishing). Although fishing is prohibited, Two-mile Reef is subjected to diver pressure and anchor damage from visiting small craft, recreational dive operators and tourists. All reef habitats at Two-mile Reef were sampled at depths between 1-18 m.

Amphitheatre and Camel's Hump are submerged rocky massifs located two kilometres seaward of Cabo de São Sebastião. They are open to fishing and SCUBA diving but turbidity is high on these reefs. Sampling at Camel's Hump ranged between 13-16 m in depth and at Amphitheatre, between 14-19 m.

Data Collection

Two fish surveys were conducted, one in February 2007 and one in November 2007. Surveys were undertaken in the late morning on a low to outgoing spring tide. Fish communities were sampled on the reefs using an underwater visual census technique adapted from Samoilys (1997) in which three divers recorded the presence of fish species on slates. A combination of diving methods was used with SCUBA being used for deeper locations and snorkelling for shallow inner lagoons. Divers conducted a 45 minute timed swim following a random path. Although the underwater visual census method is known to underestimate small and cryptic species, it was employed because it provides a means of sampling the fish community with little disturbance (Fowler, 1987; Harmelin-Vivien *et al.,* 1985). Identification of species was confirmed after sampling using appropriate reference books (King, 1996; King & Fraser 2001; Lieske & Myers 1999; Smith & Heemstra 1986).

Trophic Categorisation

Fish species were assigned to one of ten trophic categories based on classifications by Harmelin-Vivien (1979); Hiatt & Strasberg (1960); Hobson (1974) and Myers (1999) as cited by Chabanet & Durville

(2005); Durville *et al.,* (2003) and Gillibrand *et al.,* (2007). These studies used eight categories: herbivores, omnivores, browsers of sessile invertebrates, diurnal carnivores, nocturnal carnivores, piscivores, diurnal planktivores and nocturnal planktivores. In the present study, some of these categories were consolidated, viz. general carnivores and general planktivores, as the diel preference of some species was unknown (Froese & Pauly 2009; Heemstra & Heemstra 2004; King, 1996; King & Fraser 2001 and Smith & Heemstra 1986).

RESULTS

Species Richness

A total of 249 species belonging to 50 families were recorded (Table 1), of which six were cartilaginous fishes in four families and the remaining 243 species were bony fish in 46 families. The top five families according to species count were the Labridae (37 species), Acanthuridae (22 species), Chaetodontidae (22 species), Pomacentridae (17 species) and Serranidae (13 species). These five families contributed 45% to the species diversity (Table 2). Overall, 19 families were represented by only one species.

Fish families and species were not evenly distributed among all the reefs (Table 2). The top three reefs according to species richness were Two-mile Reef with 197 species, Lighthouse Reef with 103 species, and Garoupa with 101 species. Two-mile Reef also had the highest number of fish families (43) but Lighthouse Reef, despite having the second highest number of species, had relatively few families (25). Conversely, Garoupa had a relatively high number of fish families (31). All the other reefs had relatively few fish families and species; only Kingfish was better represented by 84 species in 31 families.

Table 2. Summary of the number of species and families recorded on the Bazaruto reefs. Shaded reefs are no-take zones where fishing (including artisanal fishing) is prohibited, but SCUBA diving and snorkelling are allowed. Reefs are ordered according to increasing latitude.

Reef	No. of Species	No. of Families
Twelve-mile Reef	59	21
Tubarão	44	20
Garoupa	101	31
Kingfish	84	31
Lighthouse Reef	103	25
Two-mile Reef	197	43
Camel's Hump	45	21
Amphitheatre	50	22

Trophic Structure

When all the carnivorous categories were grouped (i.e. all groups except herbivores and omnivores), they constituted 76% of the species composition (Fig. 2). Herbivores, (mostly acanthurids) and omnivores (mostly pomacentrids) each accounted for 12% of the species composition. The largest group, diurnal carnivores (27%), was dominated by labrids

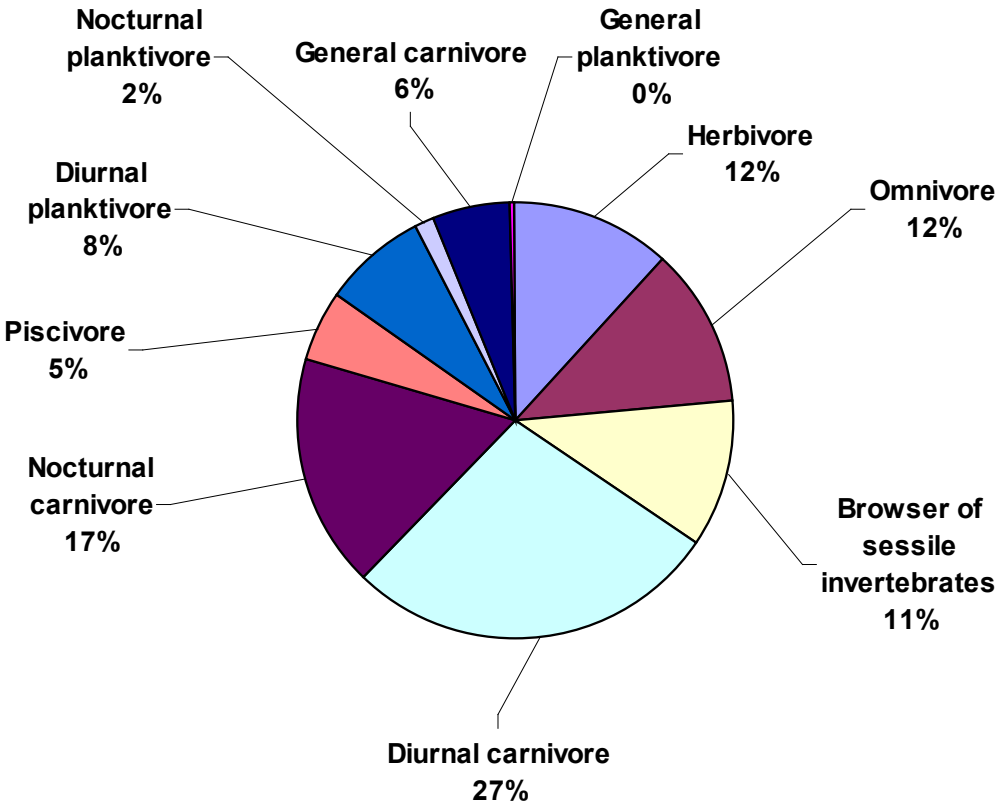

Figure 2. Overall trophic structure of Bazaruto reef fish communities.

and the nocturnal carnivores (17%) were dominated by larger lutjanids, lethrinids and serranids. Chaetodons accounted for the majority of browsers of sessile invertebrates. None of the other categories was dominated by any specific family. The piscivores, contributing 5% to the species composition, comprised mostly larger predators such as *Carcharhinus amblyrhynchos*, *Aprion virescens* and *Scomberomorus commerson*.

DISCUSSION

Species Richness

This study yielded 249 fish species in 50 families, a lower tally than other studies in the region. Durville *et al.,* (2003) recorded 332 fish species in 57 families at the Glorieuses Islands, while Chabanet & Durville (2005) listed 299 species in 55 families for Juan De Nova. Further south, Gillibrand *et al.,* (2007) counted 334 species of fish in

Table 1. Species list of the Bazaruto Archipelago on a per reef basis (depth 1-20 m). Presence is indicated by (●). H, herbivores; O, omnivores; BSI, browsers of sessile invertebrates; DC, Diurnal carnivores; NC, Nocturnal carnivores; PI, Piscivores; DP, Diurnal planktivores; NP, Nocturnal planktivores; C, General carnivores; PL, General planktivores. Shaded reefs are no-take zones where fishing (including artisanal fishing) is prohibited, but SCUBA diving and snorkelling are allowed.

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
Acanthuridae									
Acanthurus dussumieri Valenciennnes, 1835	H		●	●		●	●	●	●
Acanthurus leucocheilus Herre, 1927	H						●		
Acanthurus leucosternon Bennet, 1833	H	●		●	●	●	●	●	●
Acanthurus lineatus (Linnaeus, 1758)	H					●	●		
Acanthurus mata Russel in Cuvier, 1829	DP		●				●		
Acanthurus nigrofuscus (Forsskål, 1775)	H	●	●	●		●	●	●	●
Acanthurus tennenti Günther, 1861	H	●		●	●	●	●	●	
Acanthurus thompsoni Fowler, 1923	H				●		●		●
Acanthurus triostegus triostegus (Linnaeus, 1758)	H					●	●		
Ctenochaetus binotatus Randall, 1955	H					●	●		
Ctenochaetus strigosus (Bennet, 1828)	H			●		●	●		
Naso annulatus (Quoy & Gaimard, 1825)	H					●	●		
Naso brachycentron (Valenciennes in Cuvier and Valenciennes, 1835)	H						●		
Naso brevirostris (Cuvier, 1829)	H		●			●	●	●	
Naso hexacanthus (Bleeker, 1855)	H	●			●		●		
Naso lituratus (Forster in Bloch & Schneider, 1801)	H	●			●	●	●	●	●
Naso unicornis (Forsskål, 1775)	H	●				●	●		
Naso vlamingii (Valenciennnes, 1835)	DP	●							
Paracanthurus hepatus (Linnaeus, 1766)	DP	●				●	●		
Zebrasoma gemmatum (Valenciennnes, 1835)	H					●	●		
Zebrasoma scopas (Cuvier, 1829)	H	●				●	●		●
Zebrasoma desjardinii (Bennet, 1836)	H					●	●		
APOGONIDAE									
Apogon aureus (Lacepède, 1802)	DC				●				
AULOSTOMIDAE									
Aulostomus chinensis (Linnaeus, 1766)	PI				●		●		
BALISTIDAE									
Balistapus undulatus (Mungo Park, 1797)	DC		●	●	●	●	●		
Balistoides conspicillum (Bloch & Schneider, 1801)	DC	●			●		●		●
Balistoides viridescens (Bloch & Schneider, 1801)	DC					●	●		
Odonus niger (Rüppel, 1836)	DC	●	●	●	●			●	●
Pseudobalistes fuscus (Bloch & Schneider, 1801)	C				●				
Rhinecanthus rectangulus (Bloch & Schneider, 1801)	O				●	●			
Sufflamen chrysopterus (Bloch & Schneider, 1801)	DC		●			●	●		
Sufflamen fraenatum (Latreille, 1804)	DC	●	●	●	●	●	●		
BLENNIIDAE									
Ecsenius midas Stark, 1969	H						●	●	
Plagiotremus rhinorhynchos (Bleeker, 1852)	NP			●		●			
Plagiotremus tapeinosoma (Bleeker, 1857)	O				●		●		

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
CAESIONIDAE									
Caesio caerulaurea (Lacepède, 1801)	DP					●	●		
Caesio lunaris Cuvier, 1830	DP					●	●		
Caesio sp. Lacepède, 1801	DP			●					
Caesio xanthonota Bleeker, 1853	DP		●	●	●		●	●	
Pterocaesio sp. Bleeker, 1876	DP			●					
Pterocaesio tile (Cuvier, 1830)	DP			●			●		
CARANGIDAE									
Carangoides fulvoguttatus (Forsskål, 1775)	DC			●		●	●	●	
Caranx ignobilis (Forsskål, 1775)	DC			●					
Caranx melampygus Cuvier & Valenciennes, 1833	DC			●		●	●	●	
Caranx papuensis Alleyne & MacLeay, 1877	C				●				
Elagatis bipinnulata (Quoy & Gaimard, 1825)	DC						●	●	
Gnathanodon speciosus (Forsskål, 1775)	DC						●		
Scomberoides lysan (Forsskål, 1775)	PI						●		
CARCHARHINIDAE									
Carcharhinus amblyrhynchos (Bleeker, 1856)	PI	●					●		
Triaenodon obesus (Rüppel, 1837)	DC								●
CHAETODONTIDAE									
Chaetodon auriga Forsskål, 1775	BSI	●	●	●	●	●	●	●	●
Chaetodon blackburnii Desjardins, 1836	BSI			●					
Chaetodon dolosus Ahl, 1923	O		●	●					
Chaetodon falcula Bloch, 1793	BSI						●		
Chaetodon guttatissimus Bennet, 1832	BSI	●	●	●	●	●	●	●	●
Chaetodon interruptus Ahl, 1923	BSI	●					●	●	●
Chaetodon kleinii Bloch, 1790	BSI	●	●	●	●	●	●	●	●
Chaetodon lineolatus (Quoy & Gaimard, 1831 in Cuvier & Valenciennes)	BSI					●	●		
Chaetodon lunula (Lacepède, 1802)	BSI	●		●	●	●	●	●	●
Chaetodon madagaskariensis Ahl, 1923	BSI	●		●	●	●	●	●	●
Chaetodon melannotus (Bloch & Schneider, 1801)	BSI	●				●	●		
Chaetodon meyeri (Bloch & Schneider, 1801)	BSI	●				●	●		●
Chaetodon trifascialis Quoy & Gaimard, 1825	BSI					●	●		
Chaetodon trifasciatus (Mungo Park, 1797)	BSI	●		●		●	●	●	●
Chaetodon vagabundus Linnaeus, 1758	BSI		●	●	●	●	●	●	●
Chaetodon xanthocephalus Bennet, 1832	BSI					●	●		●
Chaetodon zanzibarensis Playfair, in Playfair & Günther, 1867	BSI						●		
Forcipiger flavissimus Jordan & McGregor, 1898	BSI			●			●	●	●
Hemitaurichthys zoster (Bennet, 1831)	DP						●		●
Heniochus acuminatus (Linnaeus, 1758)	BSI	●	●	●	●	●	●	●	●
Heniochus diphreutes Jordan, 1903	PL						●		
Heniochus monoceros Cuvier in Cuvier and Valenciennes, 1831	BSI		●				●		
CIRRHITIDAE									
Cirrhitichthys oxycephalus (Bleeker, 1855)	DC	●	●	●			●		
Paracirrhites arcatus Cuvier in Cuvier and Valenciennes, 1829	DC	●		●	●		●		
Paracirrhites forsteri (Bloch & Schneider, 1801)	DC			●		●	●		●

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
DASYATIDAE									
Himantura gerrardi (Gray, 1851)	C		•						
Taeniura lymma (Forsskål, 1775)	NC						•		
DIODONTIDAE									
Diodon liturosus Shaw, 1804	NC						•		
ECHENEIDAE									
Echeneis naucrates Linnaeus, 1758	NC	•		•			•		
EPHIPPIDAE									
Platax orbicularis (Forsskål, 1775)	O	•		•			•		•
Platax teira (Forsskål, 1775)	O						•		
Tripterodon orbis Playfair, 1867	C				•				
FISTULARIIDAE									
Fistularia commersonii Rüppel, 1838	DC					•	•		•
GOBIIDAE									
Valenciennea strigata (Broussonet, 1782)	DC			•			•		•
HAEMULIDAE									
Plectorhinchus chubbi (Thunberg, 1792)	DC			•		•	•		
Plectorhinchus plagiodesmus Fowler, 1935	NC		•		•				
Plectorhinchus flavomaculatus (Cuvier, 1830)	NC	•	•	•	•	•	•		•
Plectorhinchus gaterinus (Forsskål, 1775)	NC			•	•	•	•		
Plectorhinchus gibbosus (Lacepède, 1802)	C			•					
Plectorhinchus playfairi (Pellegrin, 1914)	DC		•	•	•	•	•	•	•
Plectorhinchus schotaf (Forsskål, 1775)	C				•				
HEMIRAMPHIDAE									
Hyporhamphus affinis (Günther, 1866)	O					•	•		
HOLOCENTRIDAE									
Myripristis botche Cuvier, 1829	NC				•				
Myripristis murdjan Forsskål, 1775	NP				•	•	•		
Neoniphon argenteus (Valenciennes, 1831)	C						•		
Neoniphon sammara Forsskål, 1775	NC					•	•		
Sargocentron caudimaculatum Rüppel, 1838	NC				•		•		
Sargocentron diadema Lacepède, 1802	NC			•		•	•		
Sargocentron spiniferum Forsskål, 1775	NC								•
KYPHOSIDAE									
Kyphosus cinerascens Forsskål, 1775	H						•		
Kyphosus sp. Lacepède, 1801	H					•			
Kyphosus vaigiensis (Quoy & Gaimard, 1825)	O				•		•		
LABRIDAE									
Anampses caeruleopunctatus Rüppel, 1829	DC			•	•	•	•		
Anampses lineatus Randall, 1972	DC			•					
Anampses meleagrides Valenciennes, 1840	DC			•	•		•		
Anampses twistii Bleeker, 1856	DC				•		•		
Bodianus anthioides Bennet, 1832	DC						•		
Bodianus axillaris Bennet, 1832	DC		•		•		•		
Bodianus bilunulatus (Lacepède, 1801)	DC				•		•		

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
Bodianus diana Lacepède, 1801	DC	●	●	●	●		●		
Cheilinus fasciatus (Bloch, 1791)	DC					●	●		
Cheilinus trilobatus Lacepède, 1801	DC					●	●		
Cheilinus undulatus Rüppel, 1835	DC	●					●		
Cheilio inermis Forsskål, 1775	DC						●		
Cirrhilabrus exquisitus Smith, 1957	DC				●		●		
Coris aygula Lacepède, 1801	DC				●		●		
Coris caudimacula Quoy & Gaimard, 1834	DC						●		
Coris cuvieri (Bennett, 1831)	DC			●			●		●
Coris frerei (Bennett, 1830)	DC			●	●	●	●		
Gomphosus caeruleus Lacepède, 1801	DC	●			●	●	●		
Halichoeres cosmetus Randall, & Smith, 1982	DC			●			●		
Halichoeres hortulanus Lacepède, 1801	DC	●		●		●	●		
Halichoeres iridis Randall, & Smith, 1982	DC			●		●	●		
Halichoeres scapularis Bennet, 1832	DC						●		
Hemigymnus fasciatus Bloch, 1792	DC				●	●	●		
Hologymnosus annulatus Lacepède, 1801	DC						●	●	
Hologymnosus doliatus Lacepède, 1801	DC						●		
Labroides bicolor Fowler & Bean, 1928	DC			●			●	●	
Labroides dimidiatus Valenciennes, 1839	DC	●	●	●	●	●	●		●
Macropharyngodon bipartitus Smith 1957	DC			●	●		●		
Macropharyngodon cyanoguttatus Randall, 1978	DC						●		
Novaculichthys taeniourus (Lacepède, 1801)	DC			●			●		
Pseudocheilinus hexataenia (Bleeker, 1857)	DC					●	●		
Pseudodax moluccanus (Valenciennes, 1840)	O			●	●		●		
Stethojulis interrupta (Bleeker, 1851)	DC						●		
Thalassoma amblycephalum Bleeker, 1856	DC			●	●	●	●	●	
Thalassoma hardwicke Bennet, 1830	DC						●		
Thalassoma hebraicum Lacepède, 1801	DC	●	●	●	●	●	●		
Thalassoma lunare Linnaeus, 1758	DC	●		●	●	●	●	●	
LETHRINIDAE									
Gnathodentex aureolineatus (Lacepède, 1802)	NC				●	●	●		
Lethrinus crocineus Smith, 1959	NC						●		
Lethrinus harak (Forsskål, 1775)	NC					●	●		
Lethrinus nebulosos (Forsskål, 1775)	NC	●					●		
Lethrinus rubrioperculatus Sato, 1978	NC	●							
Lethrinus mahsena (Forsskål, 1775)	NC						●		
Monotaxis grandoculis (Forsskål, 1775)	NC				●	●	●		
LUTJANIDAE									
Aphareus furca (Lacepède, 1801)	PI						●		
Aprion virescens Valenciennes, 1830	PI	●	●	●			●	●	●
Lutjanus argentimaculatus (Forsskål, 1775)	NC			●					
Lutjanus bohar (Forsskål, 1775)	NC	●		●		●	●		●
Lutjanus fulviflamma (Forsskål, 1775)	NC	●			●	●	●		
Lutjanus gibbus (Forsskål, 1775)	NC	●		●		●	●		
Lutjanus kasmira (Forsskål, 1775)	NC		●	●	●	●	●	●	●
Lutjanus lutjanus Bloch, 1790	NC		●	●			●		
Lutjanus notatus (Cuvier, 1828)	NC		●	●	●				
Lutjanus rivulatus (Cuvier in Cuvier and Valenciennes, 1828)	NC			●					

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
Lutjanus sebae (Cuvier, 1816)	NC			•					
Macolor niger (Forsskål, 1775)	NC						•		•
MALACANTHIDAE									
Malacanthus brevirostris Guichenot, 1848	DC			•			•		
MICRODESMIDAE									
Ptereleotris evides (Jordan & Hubbs, 1925)	DP						•		
Ptereleotris heteroptera (Bleeker, 1855)	DP						•		
MOBULIDAE									
Manta birostris (Walbaum, 1792)	DP								•
MONACANTHIDAE									
Amanses scopas (Cuvier, 1829)	BSI						•		
Cantherhines pardalis (Rüppel, 1837)	BSI						•		
Pervagor janthinosoma (Bleeker, 1854)	BSI						•		
MULLIDAE									
Mulloidichthys flavolineatus (Lacepède, 1801)	NC					•	•	•	
Mulloidichthys vanicolensis Valenciennes in Cuvier and Valenciennes, 1831)	NC			•		•	•		
Parupeneus barberinus (Lacepède, 1801)	DC					•			
Parupeneus bifasciatus (Lacepède, 1801)	C					•	•		
Parupeneus cyclostomus (Lacepède, 1801)	PI				•		•		
Parupeneus indicus (Shaw, 1803)	DC	•							
Parupeneus macronema (Lacepède, 1801)	DC			•	•	•	•		
MURAENIDAE									
Gymnothorax breedeni McCosker and Randall, 1977	C			•					
Gymnothorax favagineus Bloch & Schneider, 1801	NC			•			•	•	
Gymnothorax meleagris (Shaw, 1795)	DC			•			•		
MYLIOBATIDAE									
Aetobatus narinari (Euphrasen, 1790)	DC			•					
NEMIPTERIDAE									
Scolopsis ghanam (Forsskål, 1775)	DC			•	•	•	•	•	•
Scolopsis vosmeri (Bloch, 1792)	DC		•		•				
OSTRACIIDAE									
Ostracion cubicus (Linnaeus, 1758)	BSI		•				•	•	
Ostracion meleagris Shaw, 1796	BSI				•		•		
PEMPHERIDAE									
Parapricanthus ransonneti Steindachner, 1870	NP				•				
Pempheris adusta Bleeker, 1877	NP					•	•		
PINGUIPEDIDAE									
Parapercis hexophtalma (Cuvier, 1829)	DC				•	•	•		
PLATYCEPHALIDAE									
Papilloculiceps longiceps (Cuvier, 1829)	DC		•		•		•		
POMACANTHIDAE									
Apolemichthys trimaculatus (Lacepède, 1831)	O	•		•	•	•		•	

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
Centropyge acanthops (Norman, 1922)	O						●		
Centropyge bispinosus (Günther, 1860)	O				●		●		
Centropyge multispinis (Playfair, 1867)	O	●	●	●	●	●	●		●
Pomacanthus chrysurus (Cuvier, 1831)	O				●				
Pomacanthus imperator (Bloch, 1787)	BSI	●	●	●	●	●	●	●	●
Pomacanthus rhomboides (Gilchrist and Thompson, 1908)	C						●		
Pomacanthus semicirculatus (Cuvier in Cuvier & Valenciennes, 1831)	BSI	●	●	●	●	●	●	●	●
POMACENTRIDAE									
Abudefduf natalensis Hensley & Randall, 1983	O						●		
Abudefduf notatus Day, 1870	O					●			
Abudefduf sordidus (Forsskål, 1775)	O					●			
Abudefduf sparoides (Quoy & Gaimard, 1825)	O					●	●		
Abudefduf vaigiensis (Quoy & Gaimard, 1825)	O					●	●		
Amphiprion akallopisos Bleeker, 1853	O	●			●		●		
Amphiprion allardi Klausewitz, 1970	O				●	●	●		
Chromis dimidiata (Klunzinger, 1871)	DP	●	●	●	●	●	●		
Chromis opercularis (Günther, 1867)	DP		●						
Chromis weberi (Fowler & Bean, 1928)	DP						●		
Chrysiptera unimaculata (Cuvier, 1830)	O						●		●
Dascyllus carneus Fischer, 1885	O				●	●	●		
Dascyllus trimaculatus (Rüppel, 1829)	DP	●	●	●	●	●	●		
Plectroglyphidodon dickii (Lièvard, 1839)	O					●	●		
Plectroglyphidodon johnstonianus Fowler & Ball, 1924	O					●	●		
Plectroglyphidodon lacrymatus (Quoy & Gaimard, 1825)	O					●	●		
Pomacentrus caeruleus (Quoy & Gaimard, 1825)	O			●		●	●		
PRIACANTHIDAE									
Priacanthus hamrur (Forsskål, 1775)	NC						●		
PSEUDOCHROMIDAE									
Pseudochromis dutoiti Smith, 1955	DC	●		●			●		
SCARIDAE									
Scarus frenatus (Lacepède, 1802)	H					●	●		
Scarus ghobban Forsskål, 1775	H	●	●	●	●	●	●	●	●
Scarus rubroviolaceus Bleeker, 1847	H	●	●	●		●	●		
Scarus scaber (Valenciennes in Cuvier and Valenciennes, 1840)	H						●		
Scarus sordidus (Forsskål, 1775)	H					●	●		
Scarus tricolor Bleeker, 1847	H						●		
SCIAENIDAE									
Umbrina robinsoni Gilchrist and Thompson, 1908	C								●
SCOMBRIDAE									
Euthynnus affinis (Cantor, 1849)	C						●		
Scomberomorus commerson (Lacepède, 1800)	PI	●		●				●	●

FAMILY species	Trophic Category	Twelve-mile Reef	Tubarão	Garoupa	Kingfish	Lighthouse Reef	Two-mile Reef	Camel's Hump	Amphitheatre
SCORPAENIDAE									
Pterois miles (Bennet, 1825)	PI	●			●			●	
Scorpaenopsis venosa (Cuvier, 1829)	C			●			●		
SERRANIDAE									
Aethaloperca rogaa (Forsskål, 1775)	NC			●			●		●
Cephalopholis argus Bloch & Schneider, 1801	PI			●		●	●	●	●
Cephalopholis miniata (Forsskål, 1775)	NC			●			●		●
Epinephelus fasciatus (Forsskål, 1775)	NC							●	
Epinephelus flavocaeruleus (Lacepède, 1801)	PI					●			
Epinephelus lanceolatus (Bloch, 1790)	NC			●					
Epinephelus macrospilos (Bleeker, 1855)	C						●		
Epinephelus malabaricus (Bloch & Schneider, 1801)	NC	●		●			●		
Epinephelus tukula Morgans, 1959	NC			●			●	●	●
Nemanthias carberryi Smith, 1954	DP			●			●		
Plectropomus punctatus Quoy & Gaimard, 1824	PI						●		
Pseudanthias squamipinnis Peters, 1855	DP	●	●	●	●	●	●		
Variola louti (Forsskål, 1775)	PI	●					●		
SIGANIDAE									
Siganus luridus (Rüppell, 1829)	H						●		
Siganus sutor (Valenciennes in Cuvier and Valenciennes, 1835)	H	●	●	●	●	●	●	●	●
SPARIDAE									
Acanthopagrus bifasciatus (Forsskål, 1775)	DC			●					
SPHYRAENIDAE									
Sphyraena barracuda (Walbaum, 1792)	DC							●	
Sphyraena jello Cuvier in Cuvier and Valenciennes, 1829	NC		●	●					
Sphyraena putnamae Jordan and Seale, 1905	NC			●					
SYNODONTIDAE									
Synodus dermatogenys Fowler, 1912	PI				●				
TETRAODONTIDAE									
Arothron hispidus (Linnaeus, 1758)	NC						●		
Arothron nigropunctatus Bloch & Schneider 1801	NC				●		●		
Arothron stellatus (Bloch & Schneider 1801)	NC						●		
Canthigaster smithae Allen and Randall, 1977	O			●					
Canthigaster solandri (Richardson, 1845)	O				●				
Canthigaster valentini (Bleeker, 1853)	O		●	●	●		●		
ZANCLIDAE									
Zanclus canescens (Linnaeus, 1758)	BSI	●	●	●	●	●	●	●	●

58 families at Andavadoaka (south-west Madagascar) and van der Elst & Chater (2001), working at Bassas da India, recorded 305 species. It is not certain why Bazaruto's reefs have a lower species richness and, since the other studies in the region are not directly comparable, it is difficult to place Bazaruto in a spatial or temporal context.

Glorieuses Islands, Juan de Nova and Bassas da India are isolated coral atolls with no permanent human habitation, and consequently experience low to negligible fishing pressure, which has been reported to reduce species richness (McClanahan, 1994; Wantiez *et al.,* 1997). Their isolation from human disturbance and consequent lack of fishing would make them suitable candidates for control studies but their reefs are different from those at Bazaruto. Andavadoaka is more directly comparable with Bazaruto, being exposed to fishing pressure from a nearby fishing village and located on the mainland of Madagascar. Andavadoaka is also further south and therefore at a comparable latitude, negating the latitudinal effect on biodiversity. However, the study at Andavadoaka was conducted over one year compared to nine days at Bazaruto. A previous fish inventory of Bazaruto by van der Elst and Afonso (2008), based on a study done in the late 80s, yielded 269 species from 74 families, but their results included fishery-dependent data and are consequently not comparable to our study, which used only UVC.

The five reef types sampled in this study comprised a submerged sandstone reef, sedimented rocky patch reefs, a fringing coral reef, a barrier coral reef and two submerged rocky massifs. In terms of reef damage, diver and anchor damage were evident in the coral-covered inner lagoon of Two-mile Reef where large areas of *Acropora* were dead. Corallivorous crown-of-thorns (*Acanthaster planci*) starfish were also observed on Two-mile Reef. These have been persistent, being first recorded at Bazaruto in 1994 (Schleyer, 1998), providing further ecological pressure. Nevertheless, Two-mile Reef had the highest species richness in our study. In other studies, a reduction in hard coral cover resulting from mechanical damage has been linked to recreational SCUBA diving (Hawkins *et al.,* 1999). This reduces reef complexity which correlates with species richness (Bell & Galzin 1984; Gratwicke & Speight 2005), but without long-term monitoring, it is uncertain whether such an effect is taking place on Two-mile Reef.

Garoupa (open to fishing) is a small, flat, sandy ledge with low coral cover and little physical complexity, yet its high fish species richness and abundance was comparable to that of Lighthouse Reef but with six more fish families. The reason for this rich diversity and abundance is unclear; however, it is remarkably similar to Stringer Reef, a small sandy ledge at

Sodwana Bay in South Africa (29° 31.784' S; 32° 40.969' E), which is closed to fishing. Both reefs are similar in terms of coral cover, structural simplicity and high fish abundance (pers. obs.). At Garoupa, the piscivorous lutjanid, *Aprion virescens*, and the scombrid (mackerel), *Scomberomorus commerson*, were prevalent in the mid-water, suggesting a predator-dominated environment, but further ecological investigation of this reef is warranted.

The fish diversity at Twelve-mile Reef (submerged sandstone reef) was expected to be high, given its physical complexity, high coral cover and relative inaccessibility, being furthest offshore. Since the greatest fishing pressure on the Bazaruto reefs is believed to be caused by artisanal fishermen using non-motorised dhows, Twelve-mile Reef should experience relatively little fishing pressure because of its remoteness. High fish diversity may be associated with low fishing effort (McClanahan, 1994; Wantiez *et al.,* 1997) but did not prove the case on Twelve-mile Reef.

The submerged rocky massifs; Camel's Hump and Amphitheatre (both open to fishing) have high vertical relief but are not structurally complex and have minimal coral cover, probably due to high turbidity (Rogers, 1990). Their relatively low fish diversity may be explained by these attributes, which may also be the reason why the top five families (labrids, acanthurids, chaetodons, pomacentrids and serranids) were underrepresented.

Trophic Structure

Kulbicki (1988) suggested that trophic structure is usually constant within a region and this has been confirmed in other studies in the WIO (Table 3). Reef disturbances in the form of over-fishing, pollution or coral bleaching have been reported to cause a reduction in the number of carnivores and an increase in herbivores (Chabanet, 2002; Harmelin-Vivien, 1992). While large carnivores are targeted by fishers (Chabanet & Durville 2005), a reduction in coral cover caused by pollution (Rogers, 1990) and

Table 3. Comparison of trophic structure (%) in reef fish communities in the Western Indian Ocean (WIO).

Location	Reference	Carnivores	Omnivores	Herbivores
Tuléar	Harmelin-Vivien, 1979	74	13.5	12.5
Réunion	Chabanet, 1994	51	24	25
Mayotte	Chabanet, 2002	69	12.5	18.5
Geyser and Zéléé	Chabanet *et al*., 2002	69	16	15
Glorieuses	Durville *et al.,* 2003	73	12	15
Juan de Nova	Chabanet & Durville 2005	73	11	16
Andavadoaka	Gillibrand *et al.,* 2007	76	11	13
Bazaruto	This study	76	12	12

coral bleaching encourages the rapid growth of filamentous algae, which provides increased food for herbivores (Chabanet, 2002).

Reefs that are considered healthy usually have carnivore levels of between 60-80% (Harmelin-Vivien, 1979), as found on the Bazaruto and other reefs in the WIO (Table 3). Bazaruto had a high proportion of carnivores compared to these other studies. If one compares the Bazaruto fish communities with those in isolated environments with little or no human interference (Glorieuses – Durville *et al.,* 2003; Juan de Nova – Chabanet & Durville 2005), they appear, superficially, to be in a healthy state. However, amalgamation of the carnivorous groups in this study and in many others yields an oversimplification of the situation. Andavadoaka also has an abundance of carnivores (Gillibrand *et al.,* 2007) similar to the Bazaruto reefs, yet experiences fishing pressure and the reefs are reported to be in a degraded state following broad-scale coral bleaching (Gillibrand *et al.*, 2007). It is therefore difficult to link reef health to a simple index such as carnivore abundance.

Future studies should focus on the true trophic hierarchy in the fish communities on the Bazaruto reefs, differentiating between the higher and lower carnivores, rather than between diel preferences. Small carnivorous species (e.g., labrids, chaetodons) are the most abundant and are unlikely to be affected by fishing pressure. These smaller carnivores may even benefit from fishing because of reduced predation, giving a false impression of reef health. Although a thorough analysis of the carnivore hierarchy was lacking, the proportion of herbivores on Bazaruto's reefs was low, consistent with other reef environments in the region. This indicates a relative measure of reef health where pollution and bleaching are concerned.

CONCLUSION

The Bazaruto reefs are exposed to fishing pressure, diving and anchor damage, and crown-of-thorns (*Acanthaster planci*) starfish, yet have fish communities rich in diversity and a trophic structure similar to that of other reefs in the WIO which are considered healthy. They endured the 1998 bleaching event without substantial die-off (Schleyer & Celliers 2005). However, without a long-term quantitative monitoring programme, it is difficult to place the health of the Bazaruto reefs in context. This study, like others in the WIO, presents a representative, updated inventory of the fish communities, providing a baseline for more detailed studies. However, further studies should analyse the trophic hierarchy and include abundance measurements. A lack of directly comparable results became evident during our study, highlighting a significant gap in the regional understanding of the reef

fish populations. It is suggested that a long-term monitoring programme (Chabanet & Durville 2005), specifically adapted for Bazaruto's multiple reef-types, would be suitable for conservation planning in the area.

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