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Reef Fish Inventory of Juan De Nova's Natural Park (Western Indian Ocean)

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Abstract—This paper constitutes the first study on reef fish communities at Juan de Nova, one of the Eparses Islands in the Mozambique Channel. These remote islands, with no permanent habitation, except a small military base, represent sites which experience minimal direct human influence. Sampling was firstly done by underwater visual observations, using SCUBA diving gear, at 31 stations distributed equally over the coral reef, between depths ranging from 0-15 m, and secondly, by using an anaesthetic in littoral rockpools. A total of 299 species belonging to 55 families were recorded. Nearly half of the observed species belong to five main families: Labridae (41 species), Pomacentridae (28 species), Acanthuridae (24 species), Serranidae (22 species), and Chaetodontidae (18 species). Among the reported species, 73% are carnivores, 16% herbivores and 11% omnivores. Some families are well represented, especially the carnivores such as sharks (*Carcharhinidae,* 6 species), the groupers (*Serranidae,* 20 species) and the snappers (*Lutjanidae,* 10 species), which are common at nearly every station sampled. The presence of these carnivorous species could be related to the absence of fishing pressure in the area. However, some species known to be common in the area seemed rare (e.g. *Chaetodon trifascialis, Dascyllus carneus, Labroides bicolour*) or entirely absent (*Pseudanthias cooperi, Cephalopholis miniata, Chaetodon unimaculatus, Plectroglyphidodon johnstonianus* and *Lepidozygus tapeinosoma*). From a biogeographic point of view, this study revealed a fairly diverse reef fish community for such a small, isolated island, located on the westward extreme (~45°E, 15°S) of the Indo-Pacific. The absence or the paucity of certain species and/or families could be the consequence of the 1998 massive coral bleaching. There is a need for long-term studies in order to better understand the resilience of coral reef communities to environmental disturbances.

INTRODUCTION

In the marine ecosystem, coral reefs are among the most diverse habitats on the globe (Veron, 1995) and have the highest species diversity of all explored marine habitats (Paulay, 1997; Bellwood & Hughes, 2001). Unfortunately, many coral reefs are in serious decline; an estimated 30% are already severely damaged, and close to 60% may be lost by 2030 (Wilkinson, 2002). Over 100 countries of all regions of the world are affected by these perturbations, in particular fringing reefs in areas with high coastal human populations (Salvat, 1990). Currently, there are very few coral

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ecosystems which are isolated and which are not under direct anthropogenic pressure. Often the most pristine coral reefs are situated on islands with very small human populations or/and are difficult to access. This is the case of Juan de Nova Island, which is situated in a remote area, half way between Madagascar and Africa. As with the others Eparses Islands to which the island belongs, there are no permanent inhabitants, with the exception of a small military base. Juan de Nova therefore represents a site which experiences minimal direct human influence. Furthermore, its geographical situation is interesting in a biogeographic context since the island is located at the western limit of the Indo-Pacific region. There is general agreements over geographic gradients of species richness among fishes, coral and other coral reef biota, including latitudinal and longitudinal declines in diversity away from the Indo-Philippines "centre" in the Indo-Pacific (e.g. Springer, 1982; Paulay, 1990; Veron, 1995; Myers, 1999; Bellwood & Hughes, 2001; Roberts *et al.*, 2002) within which 2,900 reef and coastalfish species are recorded (Randall, 1998). Causes of these biodiversity gradients are based on presumed causal relationships between particular environmental variables and the dynamic population processes that give rise to species richness patterns: speciation, range expansion (founding a new population by dispersal), and range contraction (population extinction) (Bellwood & Hughes, 2001).

In the Indian Ocean, few coral reef fish checklists have been published. These include lists for Southern Madagascar (Harmelin-Vivien, 1979), Maldives (Randall & Anderson, 1993), Southern Africa (Smith & Heemstra, 1994), Oman (Randall, 1995), Mascareignes Archipelago (Fricke, 1999), Geyser and Zélee (Chabanet *et al.*, 2002), Glorieuses Islands (Durville *et al.*, 2003), Reunion Island (Letourneur *et al.*, 2004) and Rodrigues (Heemstra *et al.*, 2004). In order to begin an inventory of coral reef communities of the unexplored Eparses Islands, research started on 2002 through the IFRECOR program (Initiative Française pour les Récifs Coralliens). Reef fish inventories, using underwater visual census (UVC), have been conducted at Glorieuses Islands where 347 reef fish species were recorded between 0-15 m (Durville *et al.*, 2003; 2005; Quod *et al.*, 2004). This paper represents the first inventory of coral reef fish communities conducted at Juan de Nova.

MATERIALS AND METHODS

Study site

Eparses Islands (Glorieuses, Juan de Nova, Tromelin, Bassas da India, Europa and Tromelin) are classified as natural parks by the laws of 1975 and 1981 (Gabrié, 1998). They are spread over the southwest Indian Ocean, which is a region of complex currents. These currents are dominated by the westward flowing South Equatorial Current (SEC) and the strong Agulhas Current system along the southern coast of Africa (Beal & Bryden, 1999). The SEC reaches Madagascar between 17° and 20°S, where it bifurcates (see Lutjeharms *et al.*, 2000) and is known as the East Madagascar Current (EMC). The southerly part of the EMC contributes to flow within the Agulhas Current system (Di Marco *et al.*, 2002). The northerly part rounds Cape Amber (11°S) and contributes to the northward East African Coastal Current (EACC), the eastward Equatorial Countercurrent System (ECS) and the Mozambique Current (MC) (Fig. 1).

Juan de Nova is located in the Mozambique Channel (17°03'S, 42°45'E), at 200 km from Madagascar and 285 km from East Africa (Fig. 1). As the result of the dominant S-SE tradewinds, the contour of the island is that of an arc whose east and west ends are prolonged by sand banks. The length of the island between these two points is 6 km, and the maximum width is 1,700 m. The convex side of the arc faces the dominant S-SE winds. It is the highest place of the island, mainly composed of beach-rock and dunes attaining an altitude of 12 m. The concave side of the island, more protected, is mainly composed of sand beaches. The emerged island is about 5 km^2 while the overall coral reef structure represents a total area of 250 km^2. The whole annular coral reef structure extends offshore to 12 km from the northern part of the island and 1 to 2 km from its southern part (Fig. 2). The island has a well-

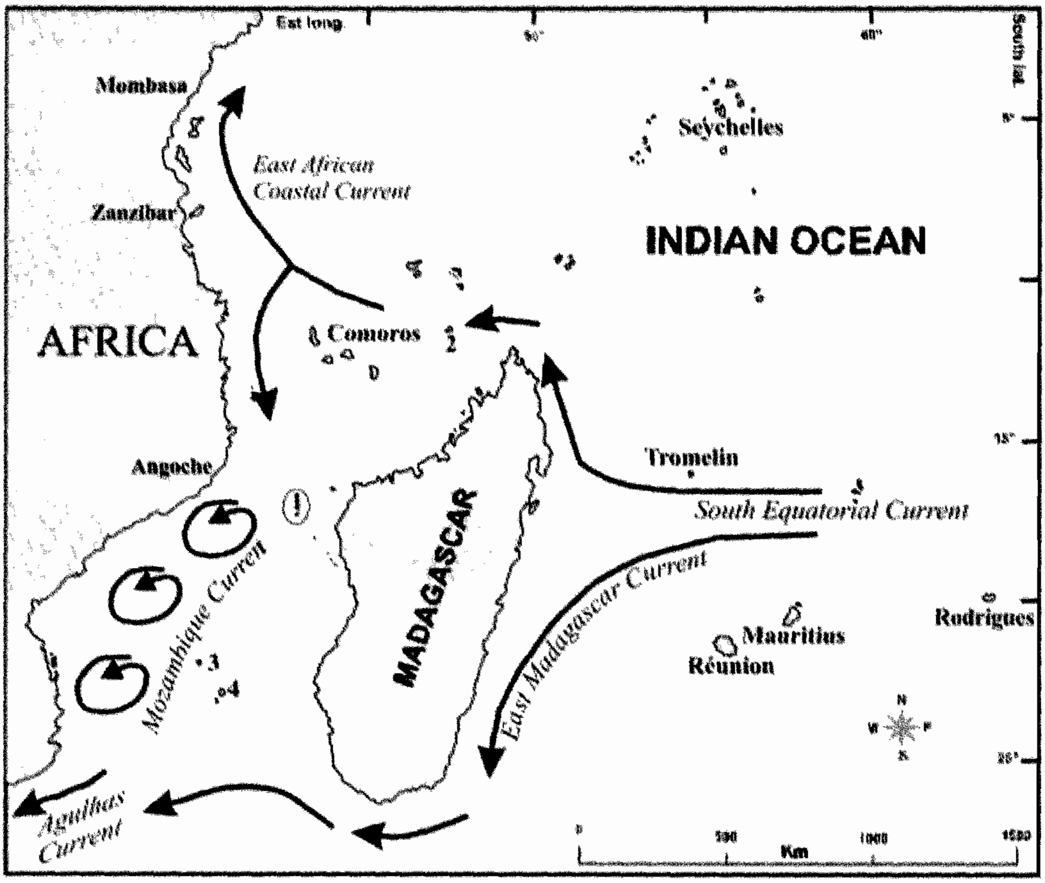

Fig. 1. Map of the Southwest Indian Ocean including the location of the Eparses Islands in the Mozambique Channel (1, 2, 3, 4) and surface current flow around Madagascar (after Beal & Bryden, 1999). 1. Juan de Nova, 2: Glorieuses, 3: Bassas da India, 4: Europa

delimited inner reef flat (1 to 2 km, 0-3 m depth) on its south side while a slope gently descends to a depth of 20 m on the northern side of the island. Tides are semidiurnal with a range up to 3 m. The living coral coverage observed ranges from 5 to 15 % (unpublished data).

METHODS

Production of the fish species inventory was achieved using two complementary techniques: underwater visual census (UVC) using SCUBA diving to sample species all around the island at depths of 10-15 m, except for the reef flat where snorkelling was used over depths of 0-3 m. An anaesthetic was used to sample rockpools species that were absent from underwater investigations or difficult to observe visually. For UVC, the diver followed a random path during 50 minutes exploring an area of about 2,500 m^2. Along this path, all species observed (juveniles and adults) were recorded on a PVC slate. Underwater photographs were taken using a digital camera for species that could not be accurately identified underwater. Such a combination of methods provides high-quality qualitative results without disturbing the fish populations (see Harmelin-Vivien *et al.*, 1985; Fowler, 1987). A total of 31 stations, distributed all around the island, were sampled (Fig. 2). Sampling of rockpools fish communities was carried out using a clove oil anaesthetic (0.05 $ml.l^{-1}$) mixed and well shaken with seawater in order to create an emulsion, as recommended by Durville and Collet (2001). The fishes are collected after a few minutes, counted, catalogued and photographed before being

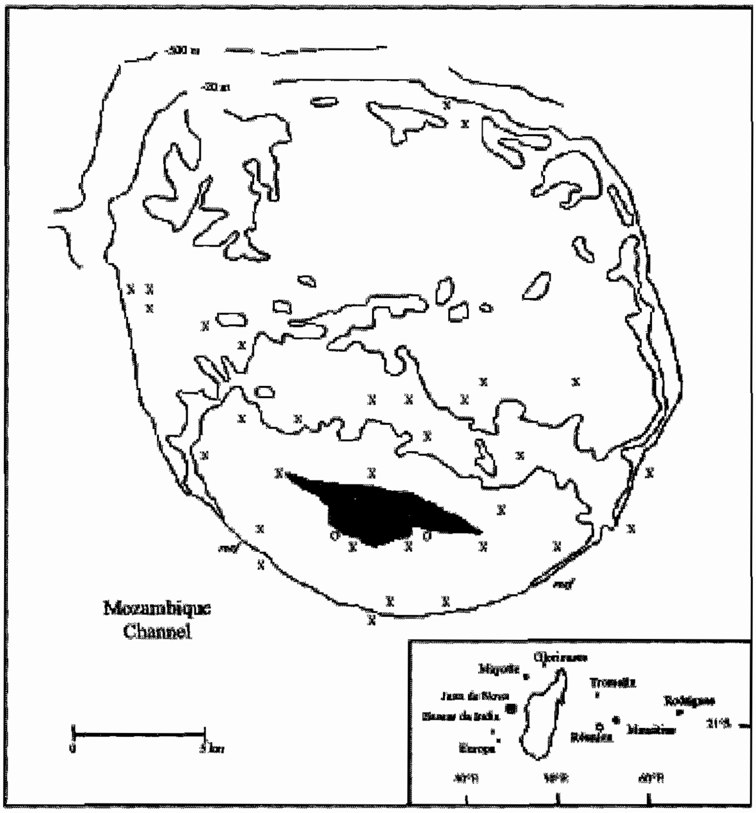

Fig. 2. Juan de Nova Island and position of sampling stations. X: stations sampled with underwater visual census; O: sampled with anaesthetic clove oil

released. Only those that could not be identified with certainty were fixed in a 5 % formalin preparation. Sampling of individual pools took between 30-40 minutes and eight stations were sampled (Fig. 2). The overall fish survey took place in May 2004, at the end of summer, and lasted 15 days.

In this study, for each species recorded, the following information were noted: (1) the biotope where the species where observed, (2) their frequency of observation, (3) their feeding behaviour. The biotopes sampled were classified as: "reef flat" referring to the internal horizontal part of the southern reef, from the reef crest to the beach; the "reef slope" designated the outer (all around the island) and inner (on the northern part of the island) reef slope; and "rockpool" referring to all pools located in the intertidal area. With respect to the frequency of observation, the term "rare" was attributed to species which were only observed once or twice during the surveys, "uncommon" for species observed between 3-10 times and "common" for species observed more than 10 times. Finally, the feeding behaviour was recorded for each species, with eight categories considered: herbivores, omnivores, browsers of sessile invertebrates (feeders mainly of coral polyps and polychaete tentacles), diurnal carnivores, nocturnal carnivores, piscivores (where adults feed only on fish), diurnal planktivores and nocturnal planktivores (after Hiatt & Strasburg, 1960; Hobson, 1974; Harmelin-Vivien, 1979; Myers, 1999). All the feeding categories, except herbivores and omnivores, could be further grouped under carnivores *sensu lato*.

In order to minimize the effect of sampling effort and help comparison between diversity observed in different areas of the Indo-Pacific, some authors recommend the use of a theoretic species richness (SR_{th}) (Werner & Allen, 1998; Allen & Werner, 2002). The calculation of SR_{th} is based on the number of species (or CFDI = Coral Fish Diversity Index) of the six most common families easily observed underwater, notably the Chaetodontidae, Pomacanthidae, Pomacentridae, Labridae, Acanthuridae and Scaridae. SR_{th} is a function of the island size and for islands < 2,000 km^2 (e.g. Juan de Nova), is calculated as follows:

$$SR_{th} = 3.39 \text{ CFDI} - 20.595$$

RESULTS

The UVC surveys and rockpool sampling yielded a total of 299 fish species, belonging to 55 families (see Table 1). Of these, eleven species were cartilaginous fishes (Chondrichtyes) while 288 species were bony fishes (Osteichtyes). Nearly half of the observed species belonged to five main families: Labridae (41 species), Pomacentridae (28 species), Acanthuridae (24 species), Serranidae (22 species), and Chaetodontidae (18 species). These five families included 44.5% of all species recorded.

The majority of species (86%) were observed on the reef slope biotope. Some species, such as *Carcharhinus albimarginatus* or *Epinephelus tukula* were observed only in this environment. Reef flat species comprised 37% of the total, among which 81 species (27%) were also observed on the reef slope, such as *Lutjanus kasmira* or *Ctenochaetus striatus.* There were 31 species (10%) that were exclusively observed over the reef flat, including *Trachinotus baillonii* and *Chrysiptera glauca.* Only 4% of the total species recorded were sampled from rockpools. These pools represent a very special biotope populated by species belonging mainly to the families Blenniidae (e.g. *Entomocrodus striatus, Istiblennius edentulus*) or Gobiidae (e.g. *Istigobius ornatus*). Only a few species were recorded both from rockpool and reef flat zones, such as *Siderea picta* and juveniles of *Abudefduf sordidus* and *Kuhlia mugil.* Other juveniles were also often observed in the rockpools. No species were found in all the three biotopes (Table 1).

Fish that were "common", observed more than 10 times during the study, accounted for 44% of the total, mainly belonging to the Lutjanidae, Acanthuridae and Carcharhinidae. Less frequently observed, or "uncommon" species (seen 3-10 times) included 33% of the total and included representatives of the Haemulidae and Cirrhiidae. "Rare" species, with fewer than two records, included 23% of the total and comprised mainly the large rays (Dasyatidae, Myliobatidae and Mobulidae), but also scorpionfishes (Scorpaenidae) or bigeyes (Priacanthidae), and *Chaetodon trifascialis, Dascyllus carneus* and *Labroides bicolor* (see Table 1).

Among the species recorded, 73% were classified as carnivores *s.l.,* which also includes piscivores, browsers of sessile invertebrates and planktivores (Fig. 3). Among this carnivorous group of fish, representatives from diurnal families (e.g. Labridae) and nocturnal families (e.g. Lutjanidae and Lethrinidae) are the most represented, with 22% and 17% of the species respectively. High ranking piscivorous predators (e.g. Carcharhinidae, Carangidae and Serranidae) accounted for 14% of the species, while diurnal fish species (e.g. Caesionidae) and nocturnal planktivores (e.g. Apogonidae and Pempheridae) together comprised up to 13% of the total and the browsers of sessile invertebrates (namely Chaetodontidae) represented 7% of the observed species. For the other diet categories, the herbivores (Acanthuridae, Scaridae) represented 16% of the species and the omnivores (Pomacentridae) 11%.

DISCUSSION

In the biogeographic context, the fish species richness of Juan de Nova is of real interest as the island is located at the western limit of the Indo-Pacific region. During the present study, 299 species were recorded, which can be compared to species richness values recorded from other south western islands in the Indian Ocean using UVC (see Table 2). Reunion has higher species richness than islands of the Mozambique Channel, probably due to the higher sampling effort, since reef fish research is permanently conducted there (e.g., Harmelin-Vivien, 1976; Letourneur, 1992; Chabanet, 1994) while in other areas, inventories are conducted over a few weeks only. In order to

Table 1. Inventory of the reef fishes of Juan de Nova (from depths of 0-15 m). Biotope indication (X) and frequency of species observations - A (rare): 1 to 2 observations; B (uncommon): 2 to 10 observations; C (common): more than 10 observations. Feedings habits (following Hiatt & Strasburg, 1960; Hobson, 1974; Harmelin-Vivien, 1979; Myers, 1999) - 1: herbivores; 2: omnivores; 3: browsers of sessile invertebrates; 4: diurnal carnivores; 5: nocturnal carnivores; 6: piscivores; 7: diurnal planktivores; 8: nocturnal planktivores

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
GINGLYMOSTOMATIDAE					
Nebrius ferrugineus (Lesson, 1830)		X		B	5
CARCHARHINIDAE					
Carcharhinus albimarginatus (Rüppell, 1837)		X		C	6
Carcharhinus amblyrhynchos (Bleeker, 1856)		X		C	6
Carcharhinus wheeleri Garrick, 1982		X		C	6
Trianodon obesus (Rüppell, 1837)		X		C	6
SPHYRNIDAE					
Sphyrna sp.		X		B	6
DASYATIDAE					
Taeniura lymna (Forsskål, 1775)		X		A	5
Taeniura melanospilos Bleeker, 1853		X		A	5
Himantura sp.	X			A	5
MYLIOBATIDAE					
Aetobatus narinari (Euphrasen, 1790)		X		A	4
MOBULIDAE					
Manta birostris (Donndorff, 1798)		X		A	7
MORINGIDAE					
Moringa microchir Bleeker, 1853			X	A	5
MURAENIDAE					
Gymnomuraena zebra (Shaw, 1797)		X		A	5
Gymnothorax flavimarginatus (Rüppell, 1830)		X		A	5
Gymnothorax javanicus (Bleeker, 1859)		X		A	5
Gymnothorax meleagris (Shaw & Nodder, 1795)		X		A	5
Siderea picta (Ahl, 1789)	X		X	C	5
CONGRIDAE					
Congridae sp.		X		A	5
SYNODONTIDAE					
Saurida gracilis (Quoy & Gaimard, 1824)	X	X		B	6
CLUPEIDAE					
Clupeidae sp.		X		C	7
Spratelloides sp.	X			C	7
BELONIDAE					
Belonidae sp.	X	X		C	6
HOLOCENTRIDAE					
Myripristis adusta Bleeker, 1853		X		B	8
Myripristis berndti Jordan & Evermann, 1903	X	X		C	8
Neoniphon sammara (Forsskål, 1775)	X			C	5

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
Sargocentron caudimaculatum (Rüppell, 1838)		X		C	5
Sargocentron diadema (Lacepède, 1802)	X	X		C	5
Sargocentron spiniferum (Forsskål, 1775)	X	X		C	5
AULOSTOMIDAE					
Aulostomus chinensis (Linnaeus, 1766)		X		B	6
FISTULARIIDAE					
Fistularia commersonii Rüppell, 1838		X		B	6
SCORPAENIDAE					
Pterois miles (Bennett, 1828)		X		A	6
Scorpenopsis diabolus (Cuvier, 1829)		X		A	6
Sebastapistes cyanostigma (Bleeker, 1856)		X		A	6
Taenianotus triacanthus Lacepède, 1802		X		A	6
SERRANIDAE					
Aethaloperca rogaa (Forsskål, 1775)		X		B	5
Cephalopolis argus Bloch & Schneider, 1801	X	X		C	6
Cephalopolis urodeta (Bloch & Schneider, 1801)		X		B	5
Epinephelus faveatus (Valenciennes, 1828)	X		A	6	
Epinephelus flavocaeruleus (Lacepède, 1801)	X	X		B	6
Epinephelus fuscoguttatus (Forsskål, 1775)		X		B	6
Epinephelus hexagonatus (Forster in Bloch & Schneider, 1801)	X	X		B	5
Epinephelus longispinis (Kner, 1864)		X		A	5
Epinephelus malabaricus (Bloch & Schneider, 1801)		X		A	6
Epinephelus melanostigma Schultz, 1953		X		A	6
Epinephelus merra Bloch, 1793	X	X		A	5
Epinephelus polyphekadion (Bleeker, 1849)		X		A	6
Epinephelus spilotoceps Schultz, 1953	X			C	5
Epinephelus tauvina (Forsskål, 1775)		X		A	6
Epinephelus tukula Morgans, 1959		X		A	6
Gracila albomarginata (Fowler & Bean, 1930)		X		A	6
Plectropomus laevis (Lacepède, 1801)		X		B	6
Plectropomus pessuliferus Fowler, 1904		X		A	6
Plectropomus punctatus Quoy & Gaimard, 1824		X		B	6
Pseudanthias evansi (Smith, 1954)		X		C	7
Pseudanthias squamipinnis (Peters, 1855)		X		C	7
Variola louti (Forsskål, 1775)		X		B	6
APOGONIDAE					
Apogon apogonoides (Bleeker, 1856)		X		C	8
Apogon aureus (Lacepède, 1802)		X		B	8
Apogon taeniophorus Regan, 1908		X		B	8
Cheilodipterus lineatus Lacepède, 1801		X		B	8
Cheilodipterus quinquelineatus Cuvier in Cuvier & Valenciennes, 1828		X		B	8
Siphamia sp.	X			A	8
TERAPONIDAE					
Therapon jarbua (Forsskål, 1775)			X	A	7
KULHIIDAE					
Kuhlia mugil (Forster in Bloch & Schneider, 1801)	X		X	B	7
PRIACANTHIDAE					
Priacanthus sp.		X		A	8

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
GERREIDAE					
Gerres oeyena (Forsskål, 1775)	X			B	4
HAEMULIDAE					
Plectorhinchus gaterinus (Forsskål, 1775)		X		B	5
Plectorhinchus vittatus (Linnaeus, 1758)	X	X		B	5
NEMIPTERIDAE					
Scolopsis ghanam		X		B	4
LUTJANIDAE					
Aphareus furca (Lacepède, 1801)		X		A	6
Aprion virescens Valenciennes in Cuvier & Valenciennes, 1830		X		B	6
Lutjanus argentimaculatus (Forsskål, 1775)		X		A	5
Lutjanus bohar (Forsskål, 1775)	X	X		C	5
Lutjanus fulvus (Forster in Bloch & Schneider, 1801)	X	X		C	5
Lutjanus gibbus (Forsskål, 1775)	X	X		C	5
Lutjanus kasmira (Forsskål, 1775)	X	X		C	5
Lutjanus monostigma (Cuvier in Cuvier & Valenciennes, 1828)	X	X		C	5
Lutjanus rivulatus (Cuvier in Cuvier & Valenciennes, 1828)	X	X		C	5
Macolor niger (Forsskål, 1775)		X		C	5
CAESIONIDAE					
Caesio caerulaurea Lacepède, 1801		X		C	7
Caesio lunaris Cuvier in Cuvier & Valenciennes, 1828		X		C	7
Caesio teres Seale, 1906		X		C	7
Caesio xanthonota Bleeker, 1853		X		C	7
Pterocaesio chrysozona (Cuvier, 1838)		X		B	7
Pterocaesio tile (Cuvier,1830)		X		A	7
LETHRINIDAE					
Gnathodentex aureolineatus (Lacepède, 1802)		X		C	5
Lethrinus cf. borbonicus Valenciennes, 1830		X		B	5
Lethrinus nebulosus (Forsskål, 1775)		X		B	5
Lethrinus obsoletus (Forsskål, 1775)		X		B	5
Lethrinus olivaceus Valenciennes, 1830		X		B	5
Lethrinus rubrioperculatus Sato, 1978	X	X		C	5
Lethrinus xanthochilus Klunzinger, 1870		X		B	5
Monotaxis grandoculis (Forsskål, 1775)	X	X		C	5
MULLIDAE					
Mulloidichthys flavolineatus (Lacepède, 1801)	X	X		C	5
Mulloidichthys vanicolensis (Valenciennes in Cuvier & Valenciennes, 1831)	X	X		C	5
Parupeneus barberinus (Lacepède, 1801)	X	X		B	4
Parupeneus cyclostomus (Lacepède, 1801)		X		C	6
Parupeneus indicus (Russell & Shaw, 1803)		X		A	4
Parupeneus macronemus (Lacepède, 1801)	X	X		C	4
Parupeneus trifasciatus (Lacepède, 1801)	X	X		B	4
KYPHOSIDAE					
Kyphosus cinerascens (Forsskål, 1775)	X	X		B	1
EPHIPPIDAE					
Platax sp.		X		A	2

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
POMACANTHIDAE					
Apolemichthys trimaculatus (Lacepède in Cuvier & Valenciennes, 1831)		X		A	2
Centropyge acanthops (Norman, 1922)		X		A	2
Centropyge bispinosus (Günther, 1860)		X		C	
Centropyge multispinis (Playfair, 1867)		X		C	2
Pomacanthus chrysurus (Cuvier, 1831)	X	X		A	2
Pomacanthus imperator (Bloch, 1787)		X		B	3
Pomacanthus semicirculatus (Cuvier in Cuvier & Valenciennes, 1831)		X		B	3
Pygoplites diacanthus (Boddaert, 1772)		X		B	3
CHAETODONTIDAE					
Chaetodon auriga Forsskål, 1775	X	X		C	3
Chaetodon benneti (Cuvier in Cuvier & Valenciennes, 1831)		X		A	3
Chaetodon falcula Bloch, 1793	X			B	3
Chaetodon guttatissimus Bennett, 1832	X	X		C	3
Chaetodon kleinii Bloch, 1790	X	X		C	3
Chaetodon lineolatus (Quoy & Gaimard in Cuvier & Valenciennes, 1831)		X		B	3
Chaetodon lunula (Lacepède, 1802)	X	X		C	3
Chaetodon madagaskariensis Ahl, 1923		X		C	3
Chaetodon melannotus (Bloch & Schneider, 1801)		X		A	3
Chaetodon meyeri Bloch & Schneider, 1801		X		B	3
Chaetodon trifascalis Quoy & Gaimard, 1825		X		A	3
Chaetodon trifasciatus trifasciatus Mungo Park, 1797		X		B	3
Chaetodon vagabundus Linnaeus, 1758		X		C	3
Chaetodon xanthocephalus Bennett, 1832	X	X		B	3
Chaetodon zanzibariensis Playfair in Playfair & Günther, 1867		X		A	3
Forcipiger longirostris (Broussonet, 1782)		X		B	2
Hemitaurichthys zoster (Bennett, 1831)		X		B	7
Heniochus monoceros Cuvier in Cuvier & Valenciennes, 1831		X		C	3
ECHENEIDAE					
Echeneis naucrates Linnaeus, 1758		X		A	5
CARANGIDAE					
Carangoides orthogrammus Jordan & Gilbert, 1882		X		A	6
Caranx ignobilis (Forsskål, 1775)		X		C	6
Caranx melampygus Valenciennes in Cuvier & Valenciennes, 1833	X	X		C	6
Caranx papuensis Alleyne & Macleay, 1877		X		A	6
Caranx sexfasciatus Quoy & Gaimard, 1825		X		C	6
Elagatis bipinnulata (Quoy & Gaimard, 1825)		X		C	6
Scomberoides lysan (Forsskål, 1775)		X		C	6
Trachinotus baillonii (Commerson & Lacepède in Lacepède, 1801)	X			C	6
Trachinotus blochii (Commerson & Lacepède in Lacepède, 1801)	X			C	6
CIRRHITIDAE					
Cirrhitichthys oxycephalus (Bleeker, 1855)		X		B	5
Paracirrhites arcatus (Parkinson in Cuvier & Valenciennes, 1829)		X		B	5
Paracirrhites forsteri (Bloch & Schneider, 1801)		X		B	5
PEMPHERIDAE					
Parapriacanthus ransonneti Steindachner, 1870		X		C	8
Pempheris vanicolensis Cuvier in Cuvier & Valenciennes, 1831		X		B	8

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
POMACENTRIDAE					
Abudefduf septemfasciatus (Cuvier, 1830)	X		X	B	2
Abudefduf sordidus (Forsskål, 1775)	X			B	2
Abudefduf sparoides (Quoy & Gaimard, 1825)	X	X		B	2
Abudefduf vaigiensis (Quoy & Gaimard, 1825)		X		C	2
Amphiprion akallopisos Bleeker, 1853	X	X		C	2
Amphiprion allardi Klausewitz, 1970		X		A	2
Chromis dimidiata (Klunzinger,1871)		X		C	7
Chromis nigrura Smith, 1960		X		C	7
Chromis opercularis (Günther, 1867)		X		C	7
Chromis ternatensis (Bleeker, 1856)		X		C	7
Chromis weberi Fowler & Bean, 1928		X		C	7
Chrysiptera annulata (Peters, 1855)		X	X	C	7
Chrysiptera biocellata (Quoy & Gaimard, 1825)	X			C	2
Chrysiptera glauca (Cuvier in Cuvier & Valenciennes, 1830)	X			C	2
Chrysiptera leucopoma (Lesson in Cuvier & Valenciennes, 1830)	X	X		C	2
Chrysiptera unimaculata (Cuvier, 1830)	X	X		C	2
Dascyllus aruanus (Linnaeus, 1758)	X			C	7
Dascyllus carneus Fischer, 1885	X	X		A	7
Dascyllus trimaculatus (Rüppell, 1829)	X	X		B	7
Neoglyphidodon melas (Cuvier, 1830)		X		C	4
Plectroglyphidodon dickii (Liénard, 1839)	X	X		C	2
Pomacentrus caeruleus Quoy & Gaimard, 1825	X	X		C	2
Pomacentrus pavo (Bloch, 1787)	X	X		C	2
Pomacentrus sulfureus Klunzinger, 1871	X	X		C	2
Pomacentrus sp.		X		A	2
Stegastes fasciolatus (Ogilby, 1889)	X	X		C	1
Stegastes nigricans (Lacepède, 1802)	X			B	1
Stegastes pelicieri Allen & Emery, 1985	X	X		C	1
LABRIDAE					
Anampses caeruleopunctatus Rüppell, 1829		X		B	4
Anampses meleagrides Valenciennes in Cuvier & Valenciennes, 1840		X		B	4
Anampses twistii Bleeker, 1856		X		C	4
Bodianus anthioides (Bennett, 1832)		X		B	4
Bodianus axillaris (Bennett, 1832)		X		C	4
Bodianus bilunulatus bilunulatus (Lacepède, 1801)		X		B	4
Bodianus diana (Lacepède, 1801)		X		C	4
Bodianus perdito (Quoy & Gaimard, 1834)		X		A	4
Cheilinus digrammus (Lacepède, 1801)		X		B	4
Cheilinus fasciatus fasciatus (Bloch, 1791)		X		B	4
Cheilinus trilobatus Commerson & Lacepède in Lacepède, 1801	X	X		C	4
Cheilinus undulatus Rüppell, 1835		X		B	4
Coris africana Smith, 1957	X	X		B	4
Coris aygula Lacepède, 1801		X		B	4
Coris caudimacula (Quoy & Gaimard, 1834)		X		C	4
Cymolutes praetextatus (Quoy & Gaimard, 1834)	X			C	4
Epibulus insidiator (Pallas, 1770)		X		B	4
Gomphusus caeruleus caeruleus Lacepède, 1801	X	X		C	4
Halichoeres cosmetus Randall & Smith, 1982		X		B	4
Halichoeres hortulanus (Lacepède, 1801)	X	X		C	4
Halichoeres iridis Randall & Smith, 1982		X		B	4
Halichoeres nebulosus (Valenciennes in Cuvier & Valenciennes, 1839)		X		B	4
Halichoeres scapularis (Bennett, 1832)	X	X		C	4

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
Hemigymnus fasciatus (Bloch, 1792)		X		B	4
Hemigymnus melapterus (Bloch, 1791)		X		B	4
Hologymnosus annulatus (Lacepède, 1801)		X		B	4
Labroides bicolor Fowler & Bean, 1928		X		A	4
Labroides dimidiatus (Valenciennes in Cuvier & Valenciennes, 1839)	X	X		C	4
Labropsis xanthonota Randall, 1981		X		A	4
Novaculichthys taeniourus (Lacepède, 1801)	X	X		B	4
Oxycheilinus bimaculatus (Valenciennes, 1840)		X		A	4
Oxycheilinus digrammus (Lacepède, 1801)		X		B	4
Pseudocheilinus hexataenia (Bleeker, 1857)		X		C	4
Pseudocheilinus octotaenia Jenkins, 1901		X		C	4
Stethojulis albovittata (Bonnaterre, 1788)	X	X		C	4
Thalassoma amblycephalum (Bleeker, 1856)		X		C	4
Thalassoma hardwicke (Bennett, 1830)	X	X		C	4
Thalassoma hebraicum (Lacepède, 1801)	X	X		C	4
Thalassoma lunare (Linnaeus, 1758)	X	X		C	4
Thalassoma trilobatum (Lacepède, 1801)	X			B	4
Xyrichtys sp.		X		A	4
SCARIDAE					
Cetoscarus bicolour (Rüppell, 1829)		X		A	1
Chlorurus sordidus (Forsskål, 1775)	X	X		C	1
Chlorurus strongylocephalus (Bleeker, 1847)	X	X		C	1
Hipposcarus harid (Forsskål, 1775)		X		B	1
Scarus caudofasciatus (Günther, 1862)		X		A	1
Scarus falcipinnis (Playfair, 1868)		X		B	1
Scarus frenatus Lacepède, 1802		X		B	1
Scarus gobhan Forsskål, 1775	X	X		C	1
Scarus niger Forsskål, 1775		X		C	1
Scarus rubroviolaceus Bleeker, 1847	X	X		C	1
Scarus russellii Valenciennes in Cuvier & Valenciennes, 1840		X		B	1
Scarus scaber Valenciennes in Cuvier & Valenciennes, 1840		X		C	1
SPHYRAENIDAE					
Sphyraena barracuda (Walbaum,1792)		X		A	6
MUGILIDAE					
Mugilidae sp.	X			B	2
PINGUIPEDIDAE					
Parapercis hexophtalma (Ehrenberg in Cuvier & Valenciennes, 1829)	X	X		B	4
BLENNIDAE					
Aspidontus taeniatus (Kessler, 1874)		X		A	4
Cirripectes sp.	X	X		B	1
Entomacrodus striatus (Quoy & Gaimard, 1836)			X	C	1
Meiacanthus sp.	X			B	1
Istiblennius dussumieri (Valenciennes, 1836)			X	C	1
Istiblennius edentulus (Schneider, 1801)			X	C	1
Istiblennius lineatus (Valenciennes, 1836)		X		B	1
Istiblennius cf meleagris (Valenciennes, 1836)			X	C	1
Istiblennius spilotus Springer & Williams, 1994			X	C	1
Plagiotremus tapeinosoma (Bleeker, 1857)		X		A	4
Salarias fasciatus (Bloch, 1786)		X		C	1

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
MICRODESMIDAE					
Nemateleotris magnifica Fowler, 1938		X		A	7
Ptereleotris evides (Jordan & Hubbs, 1925)		X		B	7
Ptereleotris microlepis (Bleeker,1856)	X			C	7
Ptereleotris zebra Fowler, 1938		X		B	7
GOBIIDAE					
Amblyeleotris cf. sungami (Klausewitz, 1969)	X			C	2
Bathygobius coalitus (Bennet, 1832)			X	A	4
Ctenogobiops cf. pomastictus Lubbock & Polunin, 1977	X			C	2
Eviota cf. bimaculata Lachner & Karnella, 1980	X			A	2
Gnatholepsis sp.	X	X		C	2
Istigobius ornatus (Rüppell, 1830)			X	C	4
Valenciennea sexguttata (Valenciennes, 1837)	X			C	4
Valenciennea strigata (Broussonet, 1782)		X		A	4
ACANTHURIDAE					
Acanthurus dussumieri Valenciennes in Cuvier & Valenciennes, 1835	X	X		C	1
Acanthurus leucosternon Bennett, 1833	X	X		C	1
Acanthurus lineatus (Linnaeus, 1758)	X	X		C	1
Acanthurus mata Russell in Cuvier, 1829		X		C	7
Acanthurus nigricauda Duncker & Mohr, 1929	X	X		C	1
Acanthurus nigrofuscus (Forsskål, 1775)	X	X		C	1
Acanthurus tennentii Günther, 1861	X	X		C	1
Acanthurus thompsoni (Fowler, 1923)		X		C	1
Acanthurus triostegus triostegus (Linnaeus, 1758)	X	X		C	1
Acanthurus xanthopterus Valenciennes in Cuvier & Valenciennes, 1835		X		C	1
Ctenochaetus striatus (Quoy & Gaimard, 1825)	X	X		C	1
Ctenochaetus strigosus (Bennett, 1828)	X	X		C	1
Naso annulatus (Quoy & Gaimard, 1825)		X		B	1
Naso brachycentron (Valenciennes in Cuvier & Valenciennes, 1835)		X		B	1
Naso brevirostris (Cuvier, 1829)		X		C	1
Naso hexacanthus (Bleeker, 1855)		X		C	1
Naso lituratus (Forster in Bloch & Schneider, 1801)	X	X		C	1
Naso thynnoides (Valenciennes, 1835)		X		A	7
Naso tuberosus Lacepède, 1801		X		C	1
Naso unicornis (Forsskål, 1775)	X	X		C	1
Naso vlamingii (Valenciennes, 1835)		X		B	7
Paracanthurus hepatus (Linnaeus, 1766)		X		A	1
Zebrasoma scopas (Cuvier, 1829)		X		A	1
Zebrasoma velifer (Bloch, 1795)	X	X		B	1
ZANCLIDAE					
Zanclus canescens (Linnaeus, 1758)	X	X		C	3
SIGANIDAE					
Siganus argenteus (Quoy & Gaimard, 1825)		X		B	1
Siganus stellatus laqueus (Bonde, 1934)		X		B	1
BOTHIDAE					
Bothus mancus (Broussonet, 1782)	X			A	4
SCOMBRIDAE					
Gymnosarda unicolor (Rüppell, 1836)	X			A	6

FAMILIES - Species - Authors	Reef flat	Reef slope	Rookpool	Frequency observations	Feeding habits
BALISTIDAE					
Balistapus undulatus (Mungo Park, 1791)		X		B	4
Balistoides conspicillum (Bloch & Schneider, 1801)		X		A	4
Balistoides viridescens (Bloch & Schneider, 1801)	X	X		A	4
Odonus niger (Rüppell, 1836)		X		B	4
Pseudobalistes flavimarginatus (Rüppell, 1829)	X			B	4
Rhinecanthus aculeatus (Linnaeus, 1758)		X	X	C	4
Rhinecanthus rectangulus (Bloch & Schneider, 1801)	X	X		B	2
Sufflamen bursa (Bloch & Schneider, 1801)		X		B	4
Sufflamen chrysopterus (Bloch & Schneider, 1801)		X		C	4
MONACANTHIDAE					
Cantherhines dumerilii (Hollard, 1854)		X		B	3
Cantherhines pardalis (Rüppell, 1837)		X		B	3
OSTRACIIDAE					
Ostracion cubicus Linnaeus, 1758	X	X		B	3
TETRAODONTIDAE					
Amblyrhynchotes sp.	X			A	5
Arothron meleagris (Commerson & Lacepède in Anonymus, 1798)		X		B	5
Arothron nigropunctatus (Bloch & Schneider, 1801)	X	X		B	5
Arothron stellatus (Commerson & Lacepède in Anonymus, 1798)		X		A	5
Canthigaster bennetti (Bleeker, 1854)		X		C	2
Canthigaster solandri (Richardson, 1844)		X		A	2
Canthigaster valentini (Bleeker, 1853)		X		A	2
DIODONTIDAE					
Diodon hystrix Linnaeus, 1758	X	X		B	5

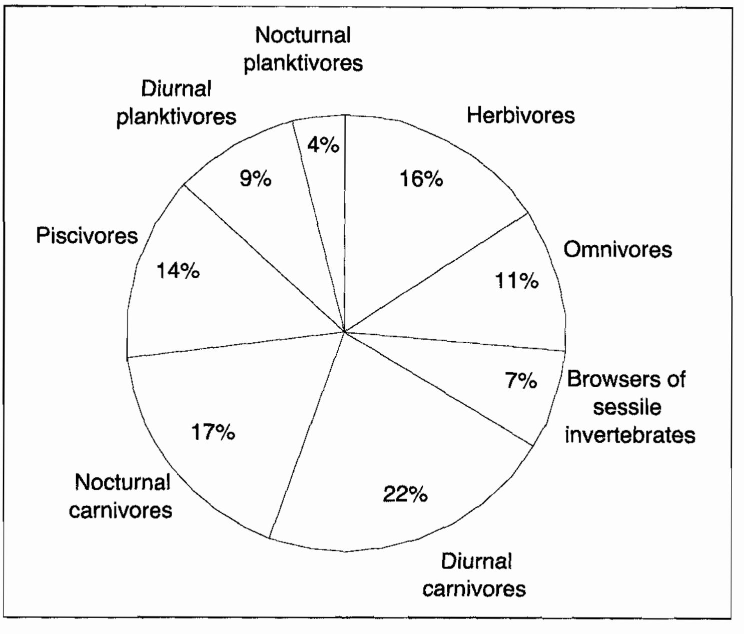

Fig. 3. Trophic structure, expressed in percentages of total number of species

minimize the effect of sampling effort, values of SR_{th} (theoretical Species Richness, see Allen & Werner, 2002) from different SW Indian Ocean islands were compared from available checklists in the literature. In the area located between 15-17°S and 42-45°E, including Mayotte, Geyser, Glorieuses, Juan de Nova, SRth values were very close (~430 sp) and relatively homogeneous, varying from 423 species (Mayotte) to 468 species (Glorieuses) (Table 2).

Connolly *et al.* (2003) predicted in their model that for the reef zone, a fish diversity is about 480 species, which is close but slightly higher than the value recorded in the present study. Hydrodynamic conditions found in SW Indian Ocean currents could enhance connectivity between islands, and then favour species richness and their homogeneity. In the SW Indian Ocean region, floats rounding Madagascar to the north frequently drifted rapidly north of the Comoros archipelago for many months with no discernable pattern, before exiting the region either to the north in the EACC and the ECS, or to the south *via* the MC (Chapman *et al.*, 2003; Fig. 1). Similarity between species composition was also found among subtidal gastropod communities between those recorded at Kenya and Madagascar (McClanahan, 2002). Small differences observed between islands could be explained by local hydrodynamic conditions and/or human pressure. For example, the maximum fish SR is recorded at Glorieuses Islands, a remote island located north of Cape Amber. This group of islands are under the influence of both a current convergence zone (Piton, 1989) and the EMC coming from the eastern part of Madagascar. By contrast, Juan de Nova is further south in the Mozambique Channel under the main influence of the MC. This current, which has a main South-North direction, could transport larvae mainly from Comoros Islands (including Mayotte) 400 km away, but also from East Africa (285 km) and Madagascar (175 km) during unusual oceanographic conditions. This could explain why even in a relatively isolated position, Juan de Nova have a relatively high species richness. Therefore, the results from this study suggest that SR does not always decrease with island size and geographical isolation, as suggested by some authors (e.g. Hourigan & Reese, 1987; Randall, 1998). The absence of fishing on Eparses islands could also favour fish diversity compared to Mayotte, a highly populated island where resources come mainly from fishing.

When the trophic structure (expressed in total number of species) of fish communities is considered, carnivores were seen to be well represented at Juan de Nova (73% of total species recorded), as they are on other islands of the SW Indian Ocean: 69% at Mayotte (Chabanet, 2002), 69% at Geyser and Zélée (Chabanet *et al.*, 2002), 73% at Glorieuses (Durville *et al.*, 2003) and 74% at Tuléar, South Madagascar (Harmelin-Vivien, 1979) (Table 3). Thus, as noted by Kulbicki (1988) and Letourneur *et al.* (1997), the contributions of the main trophic structures among fish populations remain usually relatively constant within a given geographical zone.

In this study, some families were well represented, especially those in the carnivore group, such as the sharks (Carcharhinidae, 6

Table 2. Species richness (SR) of fish communities on SW Indian Ocean coral reefs. SR_{obs}: observed SR; SR_{th}: theoretic SR calculated according Allen & Werner formula (2002). GC: geographic coordinates. *: underwater visual census (UVC) (0-15 m), **: fishing methods, *: UVC, rotenone, fishing, museum and literature records. -: no available checklist**

Sites	GC	References	SR_{obs}	SR_{th}
Glorieuses*	11°S, 47°E	Durville *et al.*, 2003	347	468
Juan de Nova*	17°S, 42°E	This study	299	423
Geyser*	12°S, 46E	Chabanet *et al.*, 2002	294	433
Mayotte (Comoros)*	13°S, 45°E	Letourneur, 1996; Chabanet, 2004	239	423
Aldabra (Seychelles)*	4°S, 55°E	Downing *et al.*, 2004	221	-
Bassas da India**	21°S, 39E	Van der Elst & Chater, 2001	305	-
Reunion***	21°S, 55°E	Letourneur *et al.*, 2005	562	565
Rodrigues***	20°S, 62°E	Heemstra *et al.*, 2004	493	410

Table 3. Trophic structure of the fish communities, expressed in percentages of total number of species on SW Indian Ocean coral reefs. Data were recorded on the outer slope (depth between 0 and 15 m)

Sites	References	Carnivores	Omnivores	Herbivores
South Madagascar	Harmelin-Vivien, 1979	74	13.5	12.5
Reunion	Chabanet, 1994	51	24	25
Mayotte	Chabanet, 2002	69	12.5	18.5
Geyser	Chabanet *et al.*, 2002	69	16	15
Glorieuses	Durville *et al.*, 2003	73	12	15
Juan de Nova	This study	73	16	11

species), the groupers (Serranidae, 20 species) and the snappers (Lutjanidae, 10 species), all present in large numbers at nearly every station. Their presence could be related to the absence of fishing pressure in the area, since carnivores are the most targeted species by artisanal and professional fishers. Nevertheless, some families like Malacanthidae or Syngnathidae have not been observed at all during the study, although they are common in this area of the Indian Ocean. Similarly, Durville *et al.* (2005) showed that the members of the Tripterygiidae family represent nearly half of the individuals in the Glorieuses rockpools, yet not a single individual of this family was sampled at Juan de Nova. Some species known to be common in the region seem to be rare, such as *Chaetodon trifascialis, Dascyllus carneus* and *Labroides bicolour,* or simply absent, such as *Pseudanthias cooperi, Cephalopholis miniata, Chaetodon unimaculatus, Plectroglyphidodon johnstonianus* and *Lepidozygus tapeinosoma.* The absence or paucity of certain species and/or families could be related to the low coral cover observed during the study (~5-15%, unpublished data). As coral reefs of Juan de Nova were reported to be flourishing 10 to 15 years ago (Downing, Laboute, pers. comm.), the present coral cover could be the consequence of the 1998 massive coral bleaching (following ENSO), which occurred in this area of the Indian Ocean (Quod, 1999; Wendling *et al.*, 2000). Rates of recovery of the resident coral communities 6 years after the 1998 bleaching event are likely to be extremely slow as observed in Mayotte (unpublished data) and Seychelles where McClanahan *et al.* (2005) reported around 2% recovery rate per year. Facing such a severe decline in coral cover, fish communities could be relatively resistant over short temporal scales (2 to 5 years) (Chabanet, 2002; Downing *et al.*, 2004), but this resilience could be disrupted through time if coral reefs do not recover. The most vulnerable fish populations are those related directly to coral for food or/and shelter such as chaetodontids and pomacentrids. In this study, *Chaetodon trifascialis* was rare and *C. unimaculatus* absent; their low frequency of observation could be related to the low coral cover observed here, as they recruit, feed and shelter in live coral as other chaetodontids (Harmelin-Vivien, 1979; Harmelin-Vivien & Bouchon-Navaro 1983; Allen *et al.*, 1998). Moreover, habitat alteration caused by the destruction of branching corals could also limit recruitment of pomacentrids associated with live coral for shelter (Randall *et al.*, 1997; Booth & Beretta, 2004). Therefore, species common throughout the region might disappear from an area, such as *Plectroglyphidodon johnstonianus* and *Lepidozygus tapeinosoma* (both not found, but expected at Juan de Nova) if recruitment from others areas does not replenish the damaged reef, especially following large-scale disturbance such as massive coral bleaching.

CONCLUSION

This study highlights the fairly high and homogeneous diversity of reef fish communities located ~45°E, 15°S at the western extreme of the Indo-Pacific region, with a peak located north of Madagascar (Glorieuses Islands). The general current patterns of the SW Indian Ocean could explain these results, enhancing the connectivity between metapopulations. The findings suggest that low fishing pressure is highly favourable for carnivorous fishes such as sharks, groupers or snappers which were very frequent during all sampling. Nevertheless, some families and/or species were rare at Juan de Nova, even though they were common in others islands of the SW Indian Ocean. These differences could be due to the relative isolation of Juan de Nova, but also to the 1998 massive bleaching event, which highly impacted SW Indian Ocean coral reefs. Indeed, some species which were not observed or rare are particularly vulnerable to decreases in coral cover as a source of food or/and shelter (e.g. chaetodontids and pomacentrids). Six years after the 1998 bleaching event, the rate of recovery of the coral communities is still extremely slow at Juan de Nova. Following a large scale disturbance such as a massive bleaching, geographical isolation of a reef ecosystem appears to be a factor that increases vulnerability and delays the recovery process of the system. There is a need for long term studies (over decades) of coral and fish assemblage dynamics at different spatial scales (from individual reef zones to regional comparisons) in order to better understand the resilience of these communities to such disturbances. Isolated islands such as Juan de Nova should be included in long term monitoring studies, because they are devoid of direct anthropogenic pressure and thus represent valuable sites that can contribute to elucidating observed natural changes. Furthermore, in a biogeographic context, it would be of real interest to monitor other remote coral reefs situated further south in the Mozambique Channel, such as Bassas da India and Europa (Eparses Islands), and establish whether the gradient of reef fish diversity does in fact decrease with latitude.

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