COMPARATIVE STUDY OF THE STRUCTURE OF COMMERCIAL FISH POPULATIONS ON MOOREA, FRENCH POLYNESIA

Rakamaly Madi Moussa
EPHE and CRIOBE[1]
(rakamany.madimoussa@univ-perp.fr)

Introduction

Coral reef populations are characterised by large spatial and time variability and high levels of diversity. Many studies have made comparisons of fish populations in coral reef environments. In French Polynesia, Galzin and Harmelin-Vivien (2000) studied qualitative and quantitative variations in fish populations in space and time. We know that coral reef populations do not remain steady over time but, rather, fluctuate at a variety of scales (e.g. daily, monthly and seasonal). In addition, we can see that such populations are also unstable on a spatial scale (Galzin 1987b). Moorea's fish population is not spread out evenly around the island (Galzin 1985; Galzin 1987a). Its distribution is linked to ecological factors such as coral cover and physical factors such as the height of the water column as well as hydrodynamic conditions (Galzin 1985). Other studies have shown that the structure of reef fish communities depends on reef geomorphology, which is a key element (Bell and Galzin 1984; Galzin 1987a; Adjeroud et al. 2002), and on different types of fishing pressure (Russ and Alcala 1989; Labrosse et al. 2000). In the Pacific, fishing pressure is strongly tied to population density (expressed as the number of inhabitants per square kilometer). In addition, increases in fishing effort result in changes in target populations (Jennings and Lock 1996) and even in the entire fish community (Jennings and Polunin 1996). Studies on the effects of fishing on reef ecosystems and fish populations have covered several variables, including size, basic outline of target fish life cycles, relative abundance of the species or the reef community's trophic structure (Jennings and Lock 1996; Jennings and Kaiser 1998). The purpose of comparative studies on fish communities of commercial interest (i.e. fish harvested as food) between a protected area and a zone subject to fishing, is to identify resource status bioindicators. This makes it possible to design tools to properly manage the resource. Among such tools are marine protected areas (MPAs), whose use has significantly grown around the world. As a tool to sustainably manage both biodiversity and fisheries yields, MPAs protect endangered species and promote tourisim activities. The reserve effect of MPAs has both spatial and temporal components (Francour 2000). The spatial component includes differences between protected and unprotected zones (Russ and Alcala 1989; Harmelin-Vivien et al. 1995; Francour 2000). The purpose of this study is to identify the effects of fishing on certain ecological characteristics of target fish communities by comparing an exploited zone and an MPA.

Materials and methods

Moorea is one of 14 islands in French Polynesia's Society Islands group (Fig. 1). Volcanic in origin, it is 25 km northwest of Tahiti at 149°50 W and 17°30 S. It is triangular in shape and has a surface area of 134 km^2 and a 70-km-long coastline. Its summit, Mount Tohivea, reaches a

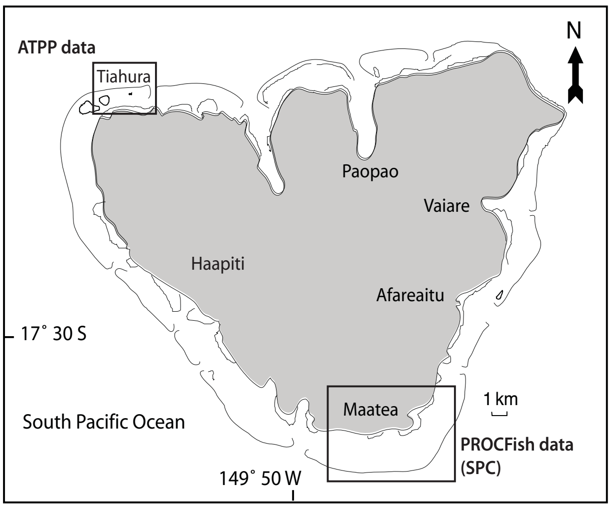

Figure 1. The two study sites on Moorea, French Polynesia.

height of 1,207 m. The island is surrounded by a barrier reef that marks the borders of a 49 km² lagoon, whose width varies from 500–1500 m, in depths of 0.5–30 m. There are 11 passes of varying depths (10–70 m) through the reef that boats use (Galzin and Pointier 1985). Tiahura, a favourite site for reef community studies since 1971 (Fig. 1), is located northwest of the island. Tiahura's transect is an imaginary 1,040-m-long line perpendicular to the coast (Fig. 2). It is divided into 22 stations forming squares 50 m long on each side, with 5 stations on the fringing reef, 9 on the barrier reef, 6 on the outer slope and 2 in the channel (Galzin 1985). In June 2006, the Pacific Regional Oceanic and Coastal Fisheries programme collected data in the village of Maatea in the southern part of Moorea (Vigliola and Boblin 2006). A total of 24 transects were set up on all the habitats (6 on the fringing reef, 6 on the intermediate reef, 6 on the barrier reef and 6 on the outer slope) (Fig. 3). For this analysis, only data from two geomorphologic units were used for each of the two sites (i.e. the outer slope and barrier reef).

Every year since 1990, a CRIOBE research team has collected qualitative and quantitative data on the barrier reef and outer reef slopes as part of the ATPP (Temporal Population Patterns Programme). Fish are counted by divers at a set distance that is ideal for monitoring fish populations without disturbing them over time (Harmelin-Vivien et al. 1985). On the barrier reef, the census zone covers a 100 m x 200 m rectangle, divided into 200 quadrates measuring 50 m x 2 m each laid out parallel to the coastline, with 10 sample units chosen randomly. On the outer slope, the arrangements are similar but there are only eight sample units.

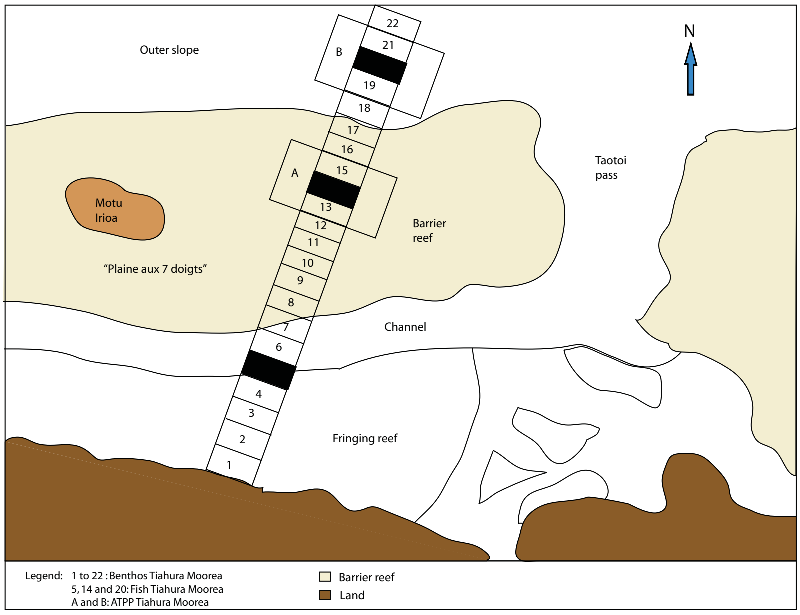

Figure 2. Position of fish stations in the Tiahura sector (A and B). Source: CRIOBE (ATPP Programme).

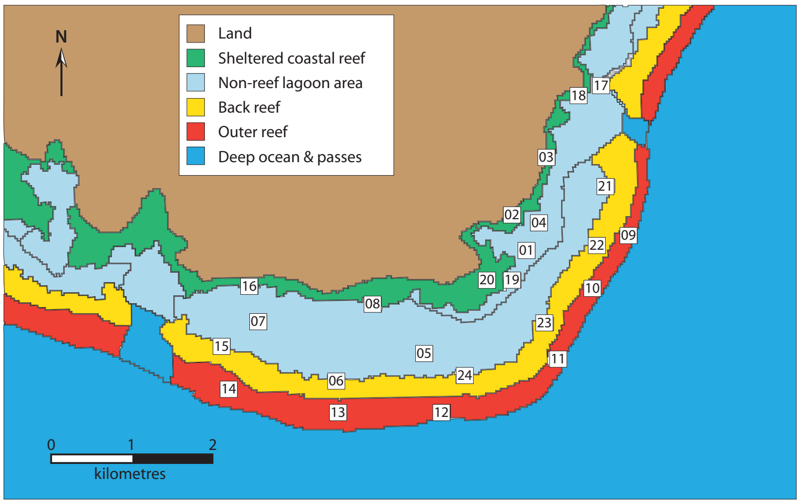

Figure 3. Location of the 24 fish census transects (PROCFish data) in the southern part of the island at Maatea. Source: Andrefouet S. (IRD Noumea) modified by Vigliola and Boblin (2006).

As part of the coastal component of the PROCFish programme and the Pacific Regional Coastal Fisheries Development Programme (CoFish), the Secretariat of the Pacific Community (SPC) conducted census surveys on Moorea in 2006. Censuses of commercial fish populations were done visually along transects at variable distances (Labrosse et al. 2003). The sampling strategy used on Moorea (Vigliola and Boblin 2006) (Fig. 3) was the same PROCFish has used in 17 countries and on more than 60 islands.

In order to compare the two datasets, PROCFish's technique was standardised with ATPP's, by setting observation distances at 1 m on either side of the 50 m transect (i.e. a surface area of 100 m^2).

Data density was calculated as follows: D = N/S

D: number of fish m^{-2}

N: number of fish observed;

S: sample surface = 100 m^2

For theses comparisons, we only analysed the data for the 22 commercial species that were common to both PROCFish and ATPP.

In order to identify changes in the trophic structures of populations subject to fishing pressure, the commercial fish selected were divided into five trophic groups: four main groups (micro-algae eaters, macro-carnivores, piscivores, macro-algae eaters and one combined group (mixed piscivores /macro-carnivores) (Kulbicki 1992).

To test the differences between trophic groups, a single-classification-category variance analysis (ANOVA) was carried out. To identify means that were significantly different, a multiple comparison student Newman-Keuls test was performed.

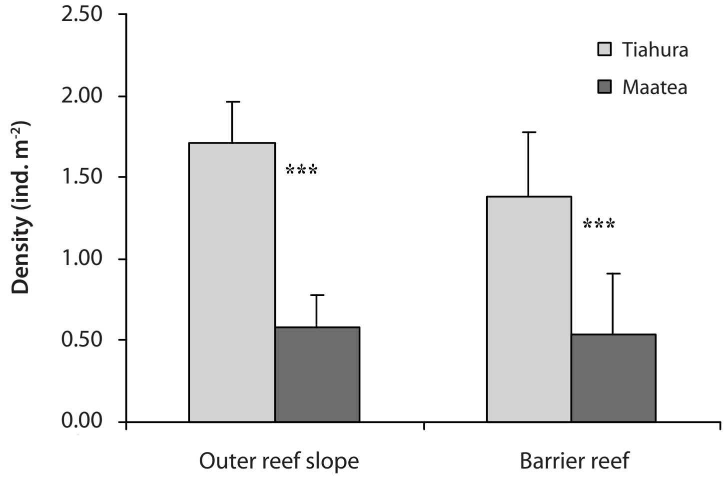

Figure 4. Mean densities (ind. m^{-2}) (± standard deviation) of food fish for the two morphological zones at each site. Meaning of codes $p < 0.000$ (***).

Results

At both sites, the highest total species richness was found on the outer slope and the lowest figures were on the barrier reef. Tiahura had a higher mean commercial species density than Maatea (Fig. 4). A T mean comparison test showed a net difference in total density between the two outer slope sites (t = -9.3038; dl = 12; $p < 0.000$) and the barrier reefs (t = -4.2742; dl = 14; $p < 0.000$).

At the Maatea barrier reef, the highest total densities were found in the families Acanthuridae (2.30 ind. m^{-2}) and Scaridae (0.24 spec. m^{-2}). The Acanthuridae family was mainly represented by *Acanthurus triostegus* (*manini*) and *Ctenochaetus striatus* (*maito*), 37% and 34% of the total density, respectively. For the Scaridae family, only *Scarus psittacus* (common parrotfish) was well represented with 7% of the total density. On the outer slope, the Acanthuridae family was once again dominant (1.61 spec. m^{-2}) with *Ctenochaetus striatus*, *Acanthurus nigroris* and *A. olivaceus* (i.e. 29%, 10%, and 7.5% of the total density, respectively). This top rank was followed by the Scaridae family (1.41 ind. m^{-2}) with *Chlorurus sordidus* and *Scarus psittacus* (i.e. 32% and 8% of the total density, respectively).

In general, there were significant differences in density between sites in the same biotope for the six main families: Acanthuridae, Labridae, Lethrinidae, Lutjanidae, Mullidae and Serranidae (Tab. 1). All of these families were more abundant at Tiahura except for Lethrinidae (t = 2.679 ; dl = 14 ; $p < 0.05$) and Lutjanidae (t = –2.846 ; dl = 5.56 ; $p < 0.05$), which were more abundant at the Maatea barrier reef.

Main species

Just 12 species (Fig. 5) accounted for 87% of the total density of the 22 target species selected for comparison at Tiahura and 96% at Maatea. They belonged to the families Acanthuridae (seven species), Serranidae (two species), Scaridae (two species), and Mullidae (one species).

The highest densities were recorded for *Ctenochaetus striatus* (*maito*) and *Acanthurus triostegus* (*manini*).

However, there were only eight significant differences between sites for the same biotope. This involved *Ctenochaetus striatus*, *Naso lituratus*, *Acanthurus nigricans*, *Cephalopholis argus* and *Acanthurus thompsoni*, whose densities were significantly higher at Tiahura. In contrast, two species had densities that were significantly higher at Maatea: *Acanthurus olivaceus* (*havari*) and *Acanthurus triostegus* (*manini*) (Fig. 5).

Trophic structure

The trophic structures study showed significant differences

Table 1. Mean densities (spec. m^{-2}) (± standard deviation) of commercial fish families at the two study sites and biotopes. Means given in bold indicate significant differences between sites for the same biotope. Meaning of codes: $p < 0.000$ (***); $p < 0.01$ (**); $p < 0.05$ (*).

	Tiahura				Maatea			
Family	Outer slope	± SD	Barrier reef	± SD	Outer slope	± SD	Barrier reef	± SD
Acanthuridae	**1.314*****	*0.173*	**0.965****	*0.125*	**0.290*****	*0.111*	**0.388****	*0.315*
Balistidae	0.003	*0.005*	0.000		0.000		0.000	
Carangidae	0.000		0.000		0.000		0.001	*0.004*
Holocentridae	0.029	*0.051*	0.026	*0.036*	0.000		0.016	*0.019*
Labridae	**0.068***	*0.046*	**0.039****	*0.028*	**0.011***	*0.019*	**0.005****	*0.005*
Lethrinidae	0.001	*0.004*	0.009*	*0.007*	0.000		0.021*	*0.012*
Lutjanidae	**0.038***	*0.045*	**0.001***	*0.003*	**0.000***		**0.013***	*0.010*
Mullidae	0.010	*0.019*	**0.070***	*0.053*	0.013	*0.015*	**0.026***	*0.016*
Scaridae	0.170	*0.088*	0.269	*0.33*	0.241	*0.132*	0.061	*0.088*
Serranidae	**0.078****	*0.030*	0.005	*0.005*	**0.029****	*0.004*	0.008	*0.013*

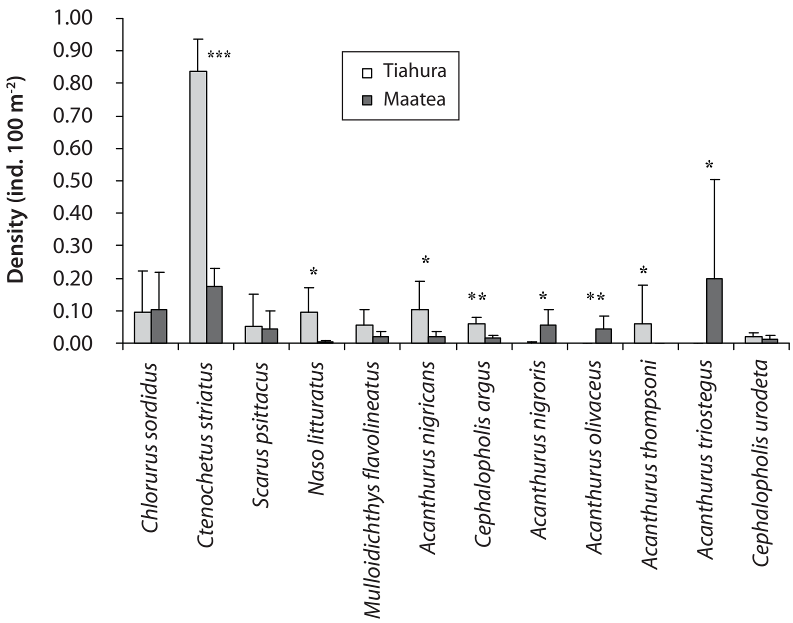

Figure 5. Mean densities (ind. m^{-2}) (± standard deviation) of food fish for the two morphological zones at each site. Meaning of codes $p < 0.000$ (***); $p < 0.01$ (**); $p < 0.05$ (*).

between fish populations at Tiahura and Maatea.

In terms of the number of species, the commercial fish trophic groups that were the most numerous at both sites were the macro-carnivores (6 species) and micro-algae eaters (10 species). In contrast, trends differed in terms of density (Fig. 6). Micro-algae eaters had the highest density followed by macro-algae eaters.

The trophic structure analysis revealed a clear predominance in density for micro- and macro-algae eaters at Tiahura. They were four to five times more numerous than macro-carnivores and piscivores. However, densities for piscivores (*Variola louti*, *Epinephelus hexagonatus*, *Cephalopholis sexmaculata*, *Cephalopholis argus*, and *Caranx melampygus*) and mixed piscivores/macro-carnivores (*Parupeneus cyclostomus*, *Elagatis bipinnulatus*, *Cephalopholis urodeta*, and *Aphareus furca*) were higher on the outer slope at Tiahura.

Macro-algae eaters mainly consisted of *Naso lituratus* (*ume tarei*), which were very abundant on the outer slope of Tiahura. The micro-algae eater group consisted of several taxa and species on the outer slope of Maatea. Finally, the macro-carnivore group covered the barrier reefs of both Tiahura and Maatea and included several families.

Conclusion

Four of the results allow us to conclude that commercial species at certain sites on Moorea are beginning to show signs of overexploitation.

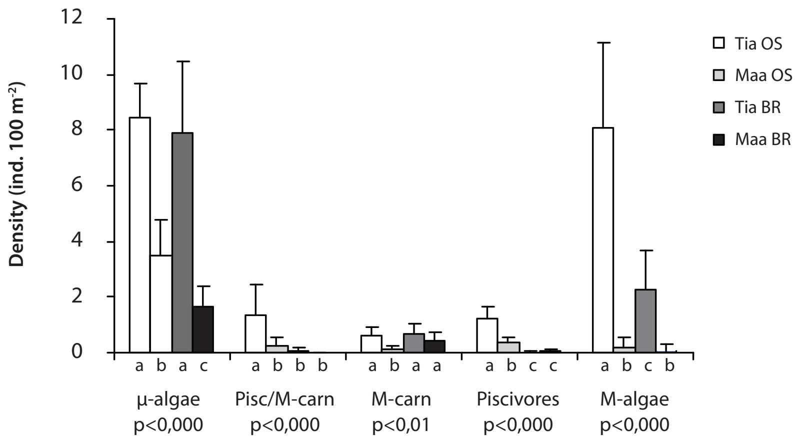

Figure 6. Differences in mean densities for each tropic group (µ-algae: micro-algae eaters, M-carn: macro-carnivores, Pisc/M-carn: piscivores and macro-carnivores, M-algae: macro-algae eaters, p: probability from the results of the single-factor ANOVA, Student Newman Keuls : histograms that have similar letters are not significantly different. TiaOS = Tiahura outer slope; TiaBR = Tiahura barrier reef and Maatea: MaaOS = Maatea outer slope; MaaBR = Maatea barrier reef).

According to the T test, Tiahura had a higher mean density for commercial species on its outer slope and barrier reef than Maatea does. The mean density of four families (Acanthuridae, Labridae, Lutjanidae and Serranidae) was higher on the outer slope of Tiahura and the mean density of three families (Acanthuridae, Labridae and Mullidae) on the barrier reef.
At the Maatea site, the comparison showed that two families (Lethrinidae and Lutjanidae) had a higher mean density on the barrier reef.

Factorial correspondence analysis of the trophic structure showed that piscivores and piscivores/macro-carnivores were associated with the outer slope of Tiahura and that micro-algae eaters were associated with the outer slope of Maatea. These results confirmed that fishing pressure at Maatea is continuous because no fish from the higher trophic levels were recorded, whereas, at Tiahura, a site that is not directly subject to fishing pressure, they were.

Small species of parrotfish, goatfish, soldierfish, rabbitfish and very small specimens of larger species, *Naso unicornis* (*ume*), comprised the major part of fishers' catches at Maatea (Vigliola and Boblin 2006). This decrease in catch size is a clear indication of generalised overexploitation of fish stocks, particularly larger fish.

According to PROCFish project's socioeconomic survey in Maatea (PROCFish/C 2006), there were 294 fishers (i.e. 31% of Maata's population and 57 fishers km^{-2}). Fishing pressure can be considered high when there are at least 5 fishers km^{-2} (McClanahan et al. 2002). This high fisher density confirmed the overexploitation of Maatea's fisheries resource.

This difference in density and spatial distribution can also be explained by habitat factors between the not-so complex, wave swept coast in the south (Maatea) and the more protected one in the north (Tiahura). The topographical complexity of the northern geomorphologic zone does, in fact, provide more shelter and greater food resources.

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1. EPHE: *École Pratique des Hautes Études* (Practical School of High Studies) – Perpignan, France; CRIOBE: *Centre de Recherches Insulaires et Observatoire de l'Environnement* (Insular Research Center and Environment Observatory) – Moorea, French Polynesia.

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Secretariat of the Pacific Community, Marine Resources Division, Information Section
BP D5, 98848 Noumea Cedex, New Caledonia
Telephone: +687 262000; Fax: +687 263818; cfpinfo@spc.int; http://www.spc.int/coastfish