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Long-term spatiotemporal variations in coral-reef fish community structure and fishing at a South Pacific atoll

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Abstract – In many atolls of the South Pacific, a shift has occurred in the past couple of decades from traditional to more intensive fishing practices. Increasing fishing pressure on coral reefs raises the need for long-term studies to understand how fish communities react to fishing practice changes. The objective of this study was to analyse the variations of reef fish communities (in terms of species richness, diversity, density and structure) during a long time lapse at Tikehau atoll (Tuamotu archipelago, French Polynesia). The same eight lagoon pinnacles were sampled in 1987 and 2003 at 6 and 12 m depth. Quantitative data were collected by visual census techniques (UVC) on 50 m × 5 m belt transects. Analyses were conducted using a multiple spatial scale (depth, pinnacle and whole lagoon) approach with a particular attention on commercial species such as Scaridae (parrotfish), Acanthuridae (surgeonfish), Lutjanidae (snapper), Lethrinidae (emperor), Serranidae (grouper). Despite an increased sampling effort between 1987 and 2003, the mean species richness per transect decreased significantly from 26.2 ± 6.2 to 21.6 ± 9.6. The mean diversity varied similarly. A stronger decrease happened at pinnacles close to the village, where fish density also decreased. Conversely, fish density, species richness and diversity increased at pinnacles less visited by inhabitants. The community structure shifted from commercial species to small site-attached species e.g. Pomacentridae (damselfish), Ptereleotridae (dartfish) as fishing reduced the abundance (and biomass) of targeted stocks. We argue that these spatiotemporal variations resulted from a drastic change in fishing practices over the 16 years period, that shifted a sustainable fishery using traditional fish traps to an unbalanced, species-threatening, selective fishery. This study underlines the need for management and for the implementation of marine protected areas (including no-take zones) in order to protect the coral reef ecosystem and favor sustainable fisheries at Tikehau atoll.

Key words: Coral reef fish communities / Diversity decrease / Species richness / Density / Fishing / South Pacific

Résumé – Dans de nombreux atolls du Pacifique Sud, une transition a eu lieu en l'espace de deux décennies entre des modes de pêche traditionnels et des techniques plus intensives. La pression de pêche croissante sur les récifs coralliens nécessite des études à long terme pour comprendre les réactions des peuplements de poissons aux changements des pratiques de pêche. L'objectif de cette étude est l'analyse des variations à long terme des peuplements de poissons (en terme de richesse spécifique, diversité, densité et structure) de l'atoll de Tikehau (Tuamotu, Polynésie Française). Les mêmes huit pinacles lagonaires ont été étudiés en 1987 et 2003 à deux profondeurs différentes (6 m et 12 m). Les données quantitatives ont été relevées à l'aide de comptages visuels sous-marins sur des transects de 50 × 5 m. Les analyses ont été réalisées à différentes échelles spatiales (profondeur, pinacles et lagon global), en portant une attention particulière aux poissons commerciaux tels que Scaridae (poissons perroquets), Acanthuridae (poissons chirurgiens), Lutjanidae (perches de mer), Lethrinidae (empereurs), Serranidae (mérous). Alors que l'effort d'échantillonnage a augmenté entre 1987 et 2003, donnant plus d'espèces recensées, la richesse spécifique moyenne par transect a diminué significativement de 26,2 ± 6,2 à 21,6 ± 9,6. La diversité spécifique moyenne a subi des variations similaires. Une

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diminution accentuée a eu lieu sur les pinacles proches du village, avec une baisse conjointe de la densité de poissons. Inversement, la densité, la richesse et la diversité spécifiques ont augmenté sur les pinacles moins fréquentés. La structure des peuplements, étudiée par une analyse des correspondances, a basculé depuis des espèces commerciales vers de petites espèces sédentaires telles que des Pomacentridae (poissons demoiselles) et Ptereleotridae (poissons fléchettes). Nous pensons que ces variations spatio-temporelles résultent d'un changement drastique de pratique de pêche en 16 ans, faisant passer une pêcherie durable basée sur des pièges traditionnels, à une pêcherie sélective qui menace certaines espèces. Cette étude souligne le besoin d'une gestion et d'une mise en place d'aires marines protégées (incluant des réserves) afin de protéger l'écosystème corallien et de favoriser une pêcherie durable sur l'atoll de Tikehau.

1 Introduction

Long-term studies on coral reef fish communities are getting more frequent. However, they focus often on reefs heavily impacted by human disturbances (e.g. Russ and Alcala 1989; Chabanet et al. 2002), cyclones, coral bleaching and other natural disturbances (e.g. Williams 1986; Letourneur et al. 1993; Chabanet 2002; Graham et al. 2007). They are also implemented to study the effects of marine reserves (Russ and Alcala 1996; Russ et al. 2003; Alcala et al. 2005; Lison de Loma et al. 2008). Since the majority of the world's coral reefs are located in countries where human populations are likely to double in the next 30–50 years, pressure on these ecosystems will inevitably increase (Mc Manus 1997), along with the most important human exploitative activity on coral reefs: fishing. Quantitative understanding of the effects of fishing using long-term studies is necessary as it helps managers to make efficient management choices. The Tuamotu atolls (French Polynesia) offer the opportunity to assess long-term changes of reef fish community structure in an environment minimally impacted by human pressure, but where shift in fishing practices is occurring.

The fish communities of Tikehau atoll have been studied on several occasions since the mid eighties, starting with selected groups of species, like herbivorous families (Harmelin-Vivien 1984), or total fish fauna (Galzin 1985, 1987). A second set of studies concerned the fish communities of the traditional fishery (Morize 1984, 1985; Blanchet et al. 1985; Caillart and Morize 1986, 1988) or the biology of target species in the fishery (Caillart et al. 1986; Caillart 1988; Morize and Caillart 1987). The total fish fauna of Tikehau lagoon was studied more intensively in 1987 (Morize et al. 1990; Caillart et al. 1994) and later in the nineties (Dufour and Harmelin-Vivien 1997). These studies yielded results of major interest on the ecology of reef fishes in atoll environments in the Central Pacific. Several years later, in 2003, Tikehau was selected for an intensive multidisciplinary field study on the relationships between fish communities and their habitat sensu lato (i.e. coral communities, space complexity and geomorphology, socio-economic environment, etc.). A novel ecosystemic approach was used to examine fishing pressure effects on fish communities, in the context of complex interactions between the natural environment, species and anthropogenic effects.

The fishery studies carried out between 1983 and 1987 in Tikehau lagoon showed a homogeneous pattern of yearly landings, with a slight increase in time (Caillart et al. 1994). However, the relative abundance of species varied considerably through this period: yields per species doubled or decreased by half without predictive sign, despite similar fishing effort and gear (non-selective fish traps). Only a handful of minor species were equally harvested year after year. The great number of species available, a common characteristic of reef fisheries (cf. Polunin and Roberts 1996), tended to buffer the large fluctuations in total catch by changes in population levels of individual species. The 2003 field trip was a good occasion, 16 years after the 1987 study, to sample the fish communities in the Tikehau lagoon, using a similar design, with the following questions in mind:

- Had the fish community changed at the lagoon scale during this long time lapse?
- If so, which community descriptors (species richness, diversity, density) were mostly affected through space and time?
- Had there been any spatial variation of the community in the lagoon during this time that could explain how the fishery functioned?

2 Materials and methods

2.1 Study sites

Fish communities were studied at eight different pinnacles (sites) in the lagoon of Tikehau atoll (Fig. 1). In October 2003, three to four stations were sampled within each site. At a depth of 12 m, one station was located on the windward side and another on the leeward side of the pinnacle. A similar design was applied at 6 m, when the size of the pinnacle was large enough. Fish were sampled all around the pinnacle when it was too small. At each station, underwater visual censuses (UVC, Harmelin-Vivien et al. 1985) were carried out on three 50 m × 5 m belt-transects. All fishes observed were identified to the species level and enumerated. The entire 50 m transect line was continuously surveyed for the occurrence of very large individuals (e.g., sharks, rays, terminal phase parrot fishes, etc) or members of highly mobile species (e.g., carangids). In the case of smaller individuals or more territorial species, each transect line was subdivided into 5 m subsections and only individuals within a given subsection were counted. When all of the fishes within a subsection had been recorded, the diver moved on to the next 5 m subsection and counted the individuals within that subsection. This process was repeated until the entire transect had been sampled. A total of 78 transects was surveyed.

The sampling design was slightly different in 1987. The same pinnacles were sampled using UVC at the same depths, but the number of stations per pinnacle and the number of transects per station related to wind exposure was different, yielding a total number of 35 transects (Table 1). These pinnacles were chosen randomly in separate geographical sectors to

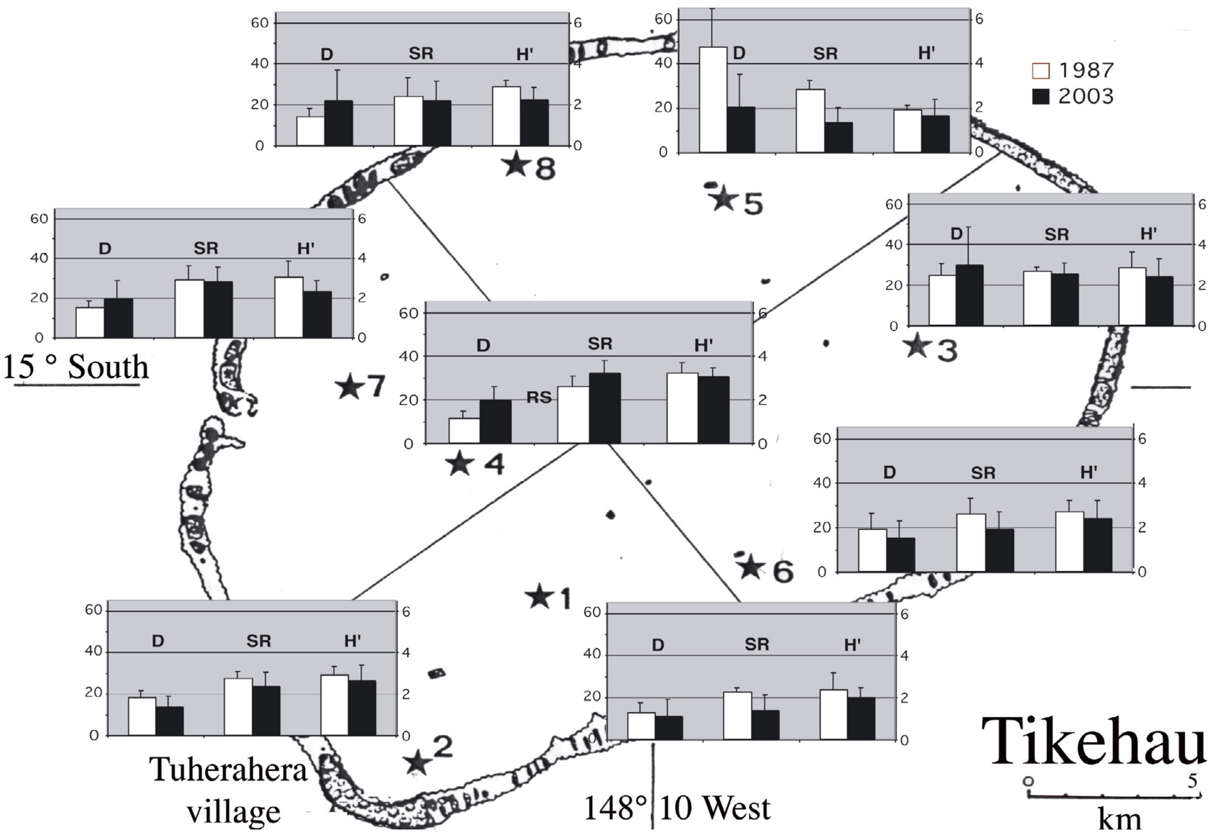

Fig. 1. Spatial variations of mean density (D, ind.m^{-2}), species richness (SR) and diversity (H') per transect in 1987 and 2003 over all pinnacles. Error bars: standard deviation, left *Y*-axis for SR, right *Y*-axis for D and H'.

Table 1. Sampling design of visual counts of reef fishes in the Tikehau lagoon in 1987 and 2003.

Pinnacle	Depth (m)	Wind exposure	Transects in 1987	Transects in 2003
1, 3, 4, 7, 8	6	R	—	3
	6	L	2	—
	12	W	—	3
	12	L	2	3
2	6	R	1	3
	12	W	—	3
	12	L	2	3
5	6	W	—	3
	6	L	2	3
	12	W	—	3
	12	L	2	3
6	6	W	2	3
	6	L	2	3
	12	W	2	3
	12	L	2	3

R = all around, W = windward, L = leeward.

ensure a homogeneous sampling of the lagoon. They were also checked for homogeneity in terms of coral vs. sand cover and size.

2.2 Data analysis

Differences between 1987 and 2003 in mean species richness, diversity (H' Shannon index) and density of fish per transect were tested using a hierarchical ANOVA (3 nested factors: year, pinnacle and depth). Spatial variations of species richness, diversity and density in the lagoon were then analysed separately in 1987 and in 2003 using one-way ANOVA and a posteriori comparisons of means (Student-Newman-Keuls test, SNK).

A correspondence analysis (Benzecri 1973) was performed on species abundance data for 32 stations, using the ADE4 statistical software (Thioulouse et al. 1997). The 32 stations correspond to the means of the number of transects censused at each pinnacle, at 6 m and at 12 m, in 1987 and 2003 (8 pinnacles × 2 depths × 2 years). Species with low abundance (< 1 individual per station for both years) were removed from the analysis.

Fish communities were also analysed relating to fishing, using a commercial/non commercial interest species classification (cf. Appendix).

Differences in fish abundance in each commercial/non commercial group were tested between and within each year using hierarchical ANOVAs (nested factors: year, pinnacle, depth and wind exposure). When a significant difference due to one factor appeared, a one-way ANOVA was carried out,

Table 2. Mean species richness (SR ± sd) and diversity (H'± sd) per transect in the lagoon of Tikehau, at 6 m and 12 m depths, in 1987 and 2003.

	1987	2003
SR	26.2 ± 6.2 (35)	21.6 ± 9.6 (78)
SR at 6 m	30.1 ± 4.2 (17)	26.6 ± 8.0 (30)
SR at 12 m	22.6 ± 5.5 (18)	18.4 ± 9.2 (48)
H'	2.7 ± 0.7 (35)	2.3 ± 0.8 (78)
H' at 6 m	3.2 ± 0.6 (17)	2.8 ± 0.7 (30)
H' at 12 m	2.3 ± 0.5 (18)	2.0 ± 0.7 (48)

( ) = number of transects.

followed by a SNK test. All statistical procedures were performed at a 0.05 confidence level.

3 Results

3.1 Decrease in species richness and diversity

The overall number of fish species recorded around the eight pinnacles in Tikehau lagoon increased from 96 in 1987 to 130 in 2003. However, a significant decrease in mean species richness at the different pinnacles occurred between 1987 and 2003 (Table 2) (hierarchical ANOVA, "year" effect: $F_{1,7}$ = 16.5, $p < 0.001$). This decrease was observed at most pinnacles in the lagoon, except pinnacle 4. The highest decrease was observed at pinnacles 1, 2 and 5.

Mean species richness in 2003 varied significantly among pinnacles ("pinnacle" effect: $F_{7,7} = 10.3$, $p < 0.001$, Fig. 1), and between depths ($F_{1,7} = 60.7$, $p < 0.001$). Fish communities were systematically more diverse at 6 m than at 12 m (Table 2). The interaction between "year" and "pinnacle" was significant ($F_{7,7} = 4.2$, $p < 0.01$). No interaction occurred between "year" and "depth", or "pinnacle" and "depth". Spatial variations of species richness (both "pinnacle" and "depth" factors) explained most of the variance, when compared to temporal variations ("year" factor effect).

Mean species diversity also decreased between 1987 and 2003 (Table 2) (hierarchical ANOVA, "year" effect: $F_{1,7}$ = 16.1, $p < 0.01$). Each pinnacle was affected by this decrease (Fig. 1). Similarly, significant differences in diversity were observed among pinnacles ($F_{7,7} = 8.4$, $p < 0.001$) and between depths ($F_{1,7} = 73.9$, $p < 0.001$). Diversity was always higher at 6 m (Table 2). Spatial variations explained a higher percentage of variance of species diversity than temporal variations.

3.2 Spatial modifications of fish communities

While no significant spatial variation of mean species richness and diversity appeared among pinnacles in 1987, clear differences were noted in 2003 (Fig. 1; species richness: $F_{7,70} = 7.13$, $p < 0.001$; diversity: $F_{7,70} = 3.35$, $p < 0.01$). The lowest species richness and diversity were at pinnacles 2, 5 and 6.

Table 3. Mean density (D ± sd, ind.m^{-2}) per transect in the lagoon of Tikehau, at 6 m and 12 m depths in 1987 and 2003.

Density (ind.m^{-2})	1987	2003
D	2.0 ± 1.3 (35)	1.9 ± 1.3 (78)
D at 6 m	2.2 ± 1.7 (17)	2.2 ± 1.2 (30)
D at 12 m	1.8 ± 0.8 (18)	1.7 ± 1.3 (48)

The mean density of fish communities did not vary significantly in the lagoon between 1987 and 2003 (Table 3), but significant spatial variations were observed among pinnacles (hierarchical ANOVA, "pinnacle" effect: $F_{7,7}$ = 5.1, $p < 0.001$, Fig. 1), showing once again the prevalence of spatial factors over temporal factors. Density also varied with depth ($F_{1,7} = 4.5$, $p < 0.05$), fish communities being always more abundant at 6 m than at 12 m (Table 3). Significant interactions were noted between "year" and "pinnacle" ($F_{7,7} = 4.4$, $p < 0.001$), and between "pinnacle" and "depth" ($F_{1,7} = 4.8$, $p < 0.001$).

In 1987, density varied significantly among pinnacles ($F_{7,70} = 7.2$, $p < 0.001$), with more fish at pinnacles 5 and 3 than at the others (Fig. 1). No spatial difference was recorded in 2003, but the p-value was nearly significant ($F_{7,70} = 2.1$, $p = 0.06$). Wind exposure did not significantly affect fish density around pinnacles, whatever the year.

The correspondence analysis performed on abundance data in 1987 and 2003 (Fig. 2) confirmed that important spatiotemporal variations occurred during the 16 years span. The first axis (explaining 20% of the total inertia) opposed mainly stations of 1987 (pinnacles 1, 2, 4, 6, 7 and 8 at 6 m, with negative coordinates), to stations of 2003 (pinnacles 2, 5, 7 and 8 at both 6 m and 12 m, with positive coordinates). The second axis (explaining 15% of the total inertia) differentiated stations of 1987 (pinnacles 2, 3, 5, 6 and 8, with positive coordinates), situated mostly at 12 m, from stations of 2003 (pinnacles 3, 4 and 6 with negative coordinates). Species associated with the first group of stations (with negative coordinates on axis 1 and mainly from 1987) were diverse, and mostly comprised commercially fished species. They were opposed on the same axis with site-attached species (mainly Pomacentridae and Ptereleotridae), related to stations from 2003.

3.3 Differential variations of commercial vs. non-commercial fish communities

No significant temporal variation in commercial or non-commercial fish density appeared between 1987 and 2003 (hierarchical ANOVA, nested factors: "year", "pinnacle" and "depth"), but a clear spatial effect was observed ("pinnacle" effect: $F_{7,7} = 6.8$, $p < 0.001$ for commercial fishes, $F_{7,7} = 5.8$, $p < 0.001$ for non-commercial species) (Fig. 3).

When analysed at the pinnacle level, commercial fish density decreased between 1987 and 2003 at pinnacle 2, the closest to the village ("depth" factor significant: $F_{1,1} = 7.8$, $p < 0.05$). The interaction with the "year" factor was significant ($F_{1,1} = 5.5$, $p < 0.05$), suggesting a depth-dependant

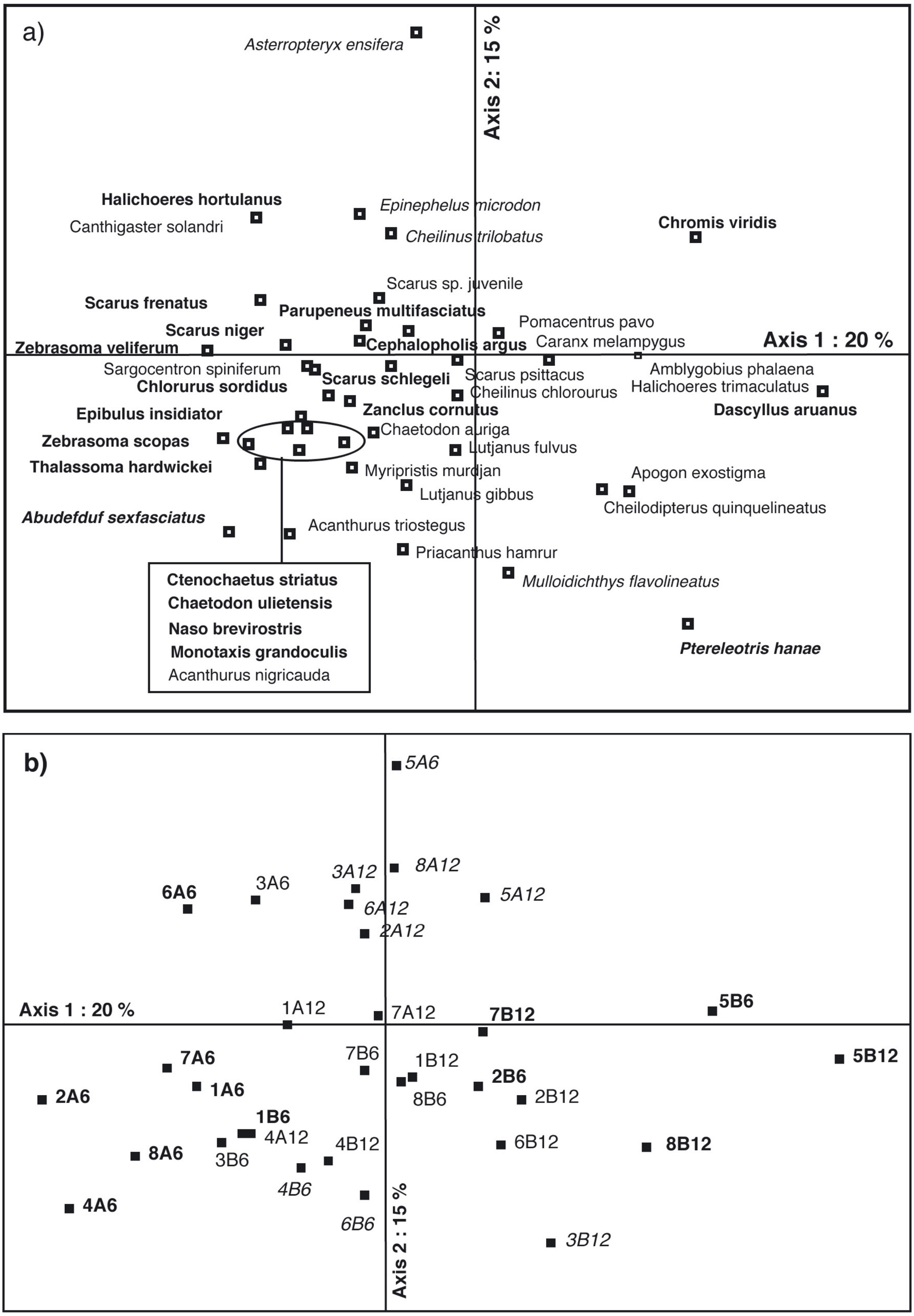

Fig. 2. Plots of species (a) and stations (b) on the first two principal axes of the correspondence analysis on fish abundance in the lagoon of Tikehau. Items in bold have strong relative contributions on axis 1, items in italics have strong relative contributions on axis 2. Stations: station/year (A : 1987, B : 2003)/depth (6 m, 12 m).

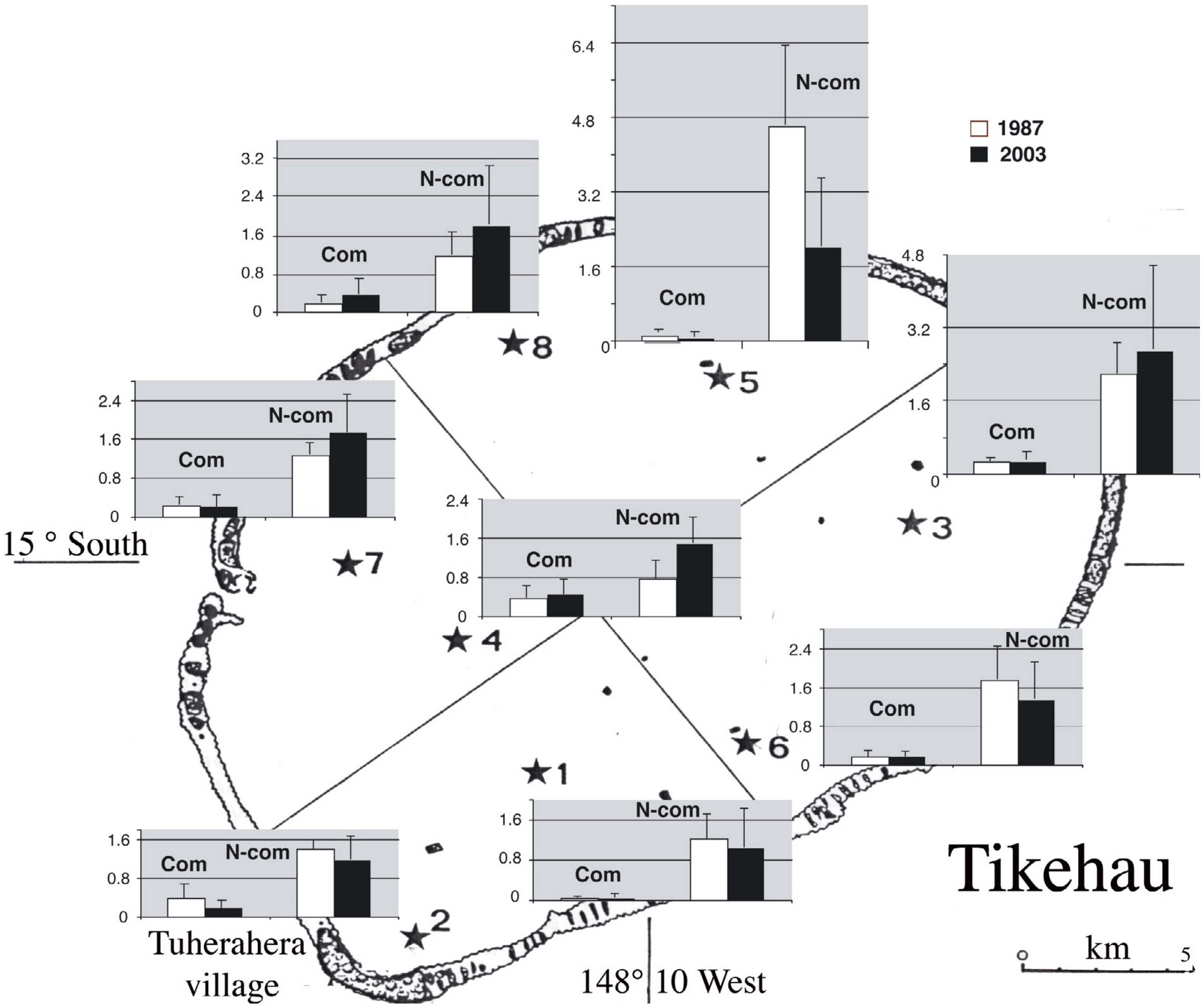

Fig. 3. Spatial variations of commercial (Com) and non-commercial (N-com) mean fish density per transect in the lagoon of Tikehau in 1987 and 2003. Error bars: standard deviation.

decrease between 1987 and 2003 occurring at 6 m. At pinnacle 5, both commercial and non-commercial species density decreased. For commercial fishes, both factors had significant effects ($F_{1,1} = 5.1$, $p < 0.05$ and $F_{1,1} = 6.8$, $p < 0.05$ respectively for "year" and "depth"). For non-commercial fishes, only "year" had a significant effect ($F_{1,1} = 10.3$, $p < 0.05$). At pinnacle 8, non-commercial fish density increased significantly with time at 6 m, but not at 12 m (significant interaction "year" × "depth", $F_{1,1} = 8.7$, $p < 0.05$). The density of commercial/non-commercial fishes did not vary significantly at the remaining pinnacles, but the general trend was a decrease for both categories at pinnacles 1, 2, 5 and 6, while an increase was noted elsewhere, especially for non-commercial species.

The density of commercial fishes varied significantly among pinnacles in 2003 (hierarchical ANOVA, "pinnacle" effect: $F_{1,7} = 4.7$, $p < 0.001$), but not between depth or wind exposure. Non-commercial fish density showed no significant difference for the three factors. Pinnacles 2 and 5 had a significantly lower density in commercial fishes than the other pinnacles (SNK test following a one-way ANOVA on log-transformed abundance data). In 1987, the situation was clearly the opposite. No significant variation was observed in the density of commercial fishes for the same factors (except wind exposure which was not considered in the hierarchical ANOVA). Conversely, the density of non-commercial fishes varied significantly with pinnacles ($F_{1,7} = 19.2$, $p < 0.001$) but not with depth. Pinnacle 5, followed by pinnacles 3 and 6, had more non-commercial fishes than other pinnacles (SNK test following a one-way ANOVA on log-transformed abundance data).

4 Discussion

The analyses performed on 1987 and 2003 data underlined the dominance of spatial over temporal variations in coral reef fish communities in the lagoon of Tikehau. Spatial heterogeneity of species richness, diversity and density of fish were more important than the temporal variations that occurred during this 16-year period.

The total number of fish species recorded during each sampling campaign increased from 1987 to 2003. The larger sampling effort in 2003 may account for this difference. Despite an increased sampling effort, the mean species richness significantly decreased in the lagoon from 1987 to 2003. Mean diversity also decreased, confirming the strength of this trend, whereas mean fish density did not vary significantly.

4.1 Temporal decrease in species richness and diversity

Several hypotheses may explain the decrease in mean species richness and diversity observed over time in Tikehau atoll. Species richness and coral cover are usually positively correlated in coral reef lagoons (Bell and Galzin 1984). Thus, an overall decrease in coral cover in Tikehau lagoon during the last 16 years may explain a decrease in fish species richness. This was not documented in Tikehau, and field observations of coral communities in 2003 (unpubl. data) did not support this hypothesis.

A change in the number of species per trophic level may have happened via trophic cascades in the context of exploitation (Jennings and Polunin 1997; Sala et al. 1998) or human disturbances (Bozec et al. 2005). However, this decrease has to be co-examined with the spatial variations observed between the two sampling campaigns, in order to understand the real nature of the shift in the fish communities.

4.2 Spatial variations of fish community descriptors between 1897 and 2003

In 1987, the mean fish density per pinnacle was higher in the eastern part of the lagoon (Morize et al. 1990). This pattern changed in 2003, resulting from an increase in the western part, particularly near the pass, combined with a decrease in the eastern part. The eastern part of the lagoon includes the village and three pinnacles nearby (pinnacles 1, 2 and 6, Fig. 1). There, the density decrease was combined with a decrease in species richness and diversity. Pinnacle 5 also followed the same significant trend, fish density being particularly affected. Rarely visited by people in 1987, this pinnacle, a small intra-lagoonal islet (motu), had become a regular weekend base camp for many villagers in 2003.

The ratio of commercial/non-commercial species showed a temporal stability at the lagoon scale, as overall fish density of both categories did not vary significantly between 1987 and 2003. However, a clear variation in spatial distribution was observed during this period for both fish categories.

A clear shift in fish community structure was illustrated by the correspondence analysis. The stations monitored in 1987 were mainly characterized by commercial species (Acanthuridae, Serranidae, Scaridae and Labridae) whereas the stations of 2003 were closely associated with non-commercial fishes (Pomacentridae and Ptereleotridae). This shift was highlighted by the absence of *Epinephelus microdon (polyphekadion)* in transects surveyed in 2003. This grouper of high commercial interest was conspicuous in 1987. A similar result was predicted by a model developed for the atolls of the Tuamotu archipelago (Mellin et al. 2006), and applied to Tikehau (Mellin et al. 2008), suggesting that the group of species affected by fishing pressure would be mostly large sized (> 50 cm) piscivores and macrocarnivores.

4.3 Shift in fish communities as a response to changes in fishing practices

The descriptors of fish communities (mean density, species richness and diversity) all showed a decrease between 1987 and 2003 at sites located near the village, or where human activity has significantly increased between the two dates. In 1987, the main fishery, consisting in passive fish traps (Morize et al. 1990), was located at the pass. Recent discussions with fishermen in charge of the traps revealed that their activity had slowed down in the last few years (unpublished data). Both the number of fishermen and effective traps had decreased. This was concomitant with an increase in fish density, species richness and diversity at the pinnacles located near the pass.

Conversely, the human population increased by 23.2% between 1988 and 2002. This happened only at the main village, while the small village at the pass, where fish trap fishermen were residing, had lost many inhabitants. A high class hotel and many guesthouses have been established in the main village, resulting in a drastic increase in tourism between 1987 and 2003. In 1987, the main fishery at the pass was non selective, while hand line and spear fishing in the lagoon were low. In contrast, the trap fishery was reduced in 2003 whereas hand lining and particularly spear fishing (a highly selective fishing practice), had notably increased. Thus, the shift observed in the fish communities of the Tikehau lagoon is likely to result from an increase in selective fishing pressure (different dominating practices of hand line and spear fishing). The vanishing of the grouper *Epinephelus microdon (polyphekadion)* from the lagoon in recent times (confirmed by talks with fishermen) confirm this hypothesis, as this species is highly vulnerable to both selective fishing practices.

The change from a sustainable passive trap fishing, which contributed to the development of a healthy grouper population in Tikehau in 1987, to selective fishing practices have also occurred in other atolls of the Tuamotu archipelago with an increasing human population. These results underline the need for better management practices, even in remote places with mild fishing pressure. The implementation of Marine Protected Areas (MPAs) in some French Polynesian islands (Moorea: Lison de Loma et al. 2008, Fakarava: Man and Biosphere – MAB UNESCO reserve) is clearly a good step forward. However, less populated atolls should also be considered in a regional management plan, including no-take areas, in order to support sustainable fisheries, a critical resource for the populations living there. Finally, these results illustrate what to expect in many atolls of the world, with the increase and shift in fishing practices.

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Appendix. Fish species recorded around pinnacles in Tikehau lagoon in 1987 and 2003. C: commercial species.

Family	Species	1987	2003	Com
Acanthuridae	*Acanthurus blochii*		x	-
	Acanthurus glaucopareius	x	x	-
	Acanthurus mata	x	x	C
	Acanthurus nigricauda	x	x	-
	Acanthurus nigrofuscus		x	-
	Acanthurus nigroris		x	-
	Acanthurus olivaceus		x	-
	Acanthurus triostegus	x	x	-
	Acanthurus xanthopterus	x	x	C
	Ctenochaetus binotatus		x	-
	Ctenochaetus striatus	x	x	-
	Ctenochaetus strigosus		x	-
	Naso annulatus	x	x	C
	Naso brevirostris	x	x	C
	Naso hexacanthus	x		C
	Naso lituratus	x	x	C
	Naso unicornis	x	x	C
	Naso vlamingi	x	x	C
	Zebrasoma scopas	x	x	-
	Zebrasoma veliferum	x	x	-
Apogonidae	*Apogon exostigma*		x	-
	Apogon nigrofasciatus		x	-
	Apogon sp.		x	-
	Cheilodipterus macrodon		x	-
	Cheilodipterus quinquelineatus	x	x	-
Balistidae	*Balistapus undulatus*	x	x	-
	Balistoides viridescens	x	x	C
	Pseudobalistes flavimarginatus		x	-
	Rhinecanthus aculeatus	x	x	-
Blenniidae	*Plagiotremus laudandus*		x	-
	Plagiotremus tapeinosoma		x	-
Carangidae	*Carangoides orthogrammus*	x		C
	Caranx ignobilis		x	C
	Caranx melampygus	x	x	C
	Caranx papuensis		x	C
Carcharhinidae	*Gnathanodon speciosus*		x	C
Chaetodontidae	*Carcharhinus melanopterus*	x	x	-
	Chaetodon auriga	x	x	C
	Chaetodon citrinellus	x	x	-
	Chaetodon ephippium	x	x	-
	Chaetodon lunula	x	x	-
	Chaetodon striatus	x		-
	Chaetodon trifascialis		x	-
	Chaetodon trifasciatus	x	x	-
	Chaetodon ulietensis	x	x	-
	Heniochus monoceros	x		-

Appendix. Continued.

Family	Species	1987	2003	Com
Echeneididae	*Echeneis naucrates*	x	x	-
Ephippidae	*Platax orbicularis*		x	C
Fistulariidae	*Fistularia commersonii*	x	x	-
	Fistularia petimba		x	-
Gobiidae	*Amblygobius phalaena*	x	x	-
	Asterropteryx ensifera	x	x	-
Ptereleotridae	*Ptereleotris hanae*	x	x	-
Holocentridae	*Myripristis adusta*		x	C
	Myripristis kuntee	x	x	-
	Myripristis murdjan	x	x	-
	Myripristis violacea	x	x	-
	Myripristis sp.	x		-
	Neoniphon opercularis	x		-
	Neoniphon sammara	x	x	-
	Sargocentron diadema		x	C
	Sargocentron spiniferum	x	x	C
Labridae	*Anampses geographicus*		x	-
	Cheilinus chlorourus	x	x	-
	Cheilinus trilobatus	x	x	-
	Cheilinus undulatus	x		-
	Coris aygula		x	-
	Coris gaimard	x	x	-
	Epibulus insidiator	x	x	-
	Gomphosus varius	x	x	-
	Halichoeres chlorourus	x		-
	Halichoeres hortulanus	x	x	-
	Halichoeres marginatus		x	-
	Halichoeres trimaculatus	x	x	-
	Labroides bicolor		x	-
	Labroides dimidiatus	x	x	-
	novaculichthys taeniourus	x	x	-
	Pseudocheilinus evanidus		x	-
	Stethojulis bandanensis	x	x	-
	Stethojulis strigive-ter		x	-
	Thalassoma amblycephalum	x	x	-
	Thalassoma hardwickei	x	x	-
	Thalassoma quinquevittatum	x		-
	Wetmorella albofasciata		x	-
Lethrinidae	*Gnathodentex aureolineatus*	x	x	-
	Lethrinus amboinensis	x		C
	Lethrinus miniatus	x		C
	Lethrinus nebulosus		x	C
	Lethrinus olivaceus		x	C
	Monotaxis grandoculis	x	x	C
Lutjanidae	*Lutjanus fulvus*	x	x	C
	Lutjanus gibbus	x	x	C
	Lutjanus kasmira		x	C
	Lutjanus monostigma	x	x	C
Monacanthidae	*Cantherhines dumerilii*		x	-
Mullidae	*Mulloidichthys flavolineatus*	x	x	C
	Mulloidichthys vanicolensis	x		C
	Parupeneus barberinus	x	x	C
	Parupeneus bifasciatus	x	x	C
	Parupeneus cyclostomus		x	C
	Parupeneus multifasciatus	x	x	C
	Parupeneus pleurostigma		x	C
	Parupeneus porphyreus	x		C

Appendix. Continued.

Family	Species	1987	2003	Com
Muraenidae	*Gymnothorax javanicus*	x	x	-
Ostraciidae	*Ostracion cubicus*	x	x	-
	Ostracion meleagris	x		-
Pomacanthidae	*Centropyge flavissimus*	x	x	-
	Pygoplites diacanthus	x	x	-
Pomacentridae	*Abudefduf sexfasciatus*	x	x	-
	Chromis viridis	x	x	-
	Dascyllus aruanus	x	x	-
	Dascyllus trimaculatus		x	-
	Pomacentrus pavo	x	x	-
	Stegastes nigricans	x		-
Priacanthidae	*Priacanthus hamrur*		x	C
Scaridae	*Calotomus carolinus*		x	C
	Cetoscarus bicolor	x	x	C
	Chlorurus microrhinos	x	x	C
	Chlorurus sordidus	x	x	-
	Hipposcarus longiceps	x	x	C
	Leptoscarus vaigiensis		x	-
	Scarus altipinnis	x	x	-
	Scarus forsteri	x		-
	Scarus frenatus	x		-
	Scarus ghobban	x	x	C
	Scarus globiceps	x	x	-
	Scarus niger	x	x	-
	Scarus oviceps	x		-
	Scarus psittacus	x	x	-
	Scarus rivulatus		x	-
	Scarus rubroviolaceus		x	-
	Scarus schlegeli	x	x	-
	Scarus sp.	x	x	-
	Scarus sp. *juvenile*		x	-
Serranidae	*Cephalopholis argus*	x	x	C
	Epinephelus merra	x	x	C
	Epinephelus microdon (polyphekadion)	x		C
Sphyraenidae	*Sphyraena forsteri*		x	C
Synodontidae	*Saurida gracilis*		x	-
	Synodus variegatus		x	-
Tetraodontidae	*Arothron hispidus*		x	-
	Arothron meleagris		x	-
	Arothron stellatus		x	-
	Canthigaster amboinensis		x	-
	Canthigaster bennetti	x	x	-
	Canthigaster solandri	x	x	-
	Canthigaster valentini	x		-
Zanclidae	*Zanclus cornutus*	x	x	-

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