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Characterization and management of informal fisheries confronted with socio-economic changes in New Caledonia (South Pacific)

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ABSTRACT

On the rural north-west coast of New Caledonia, the settlement of a major mining complex is expected to cause rapid and important socio-economic changes, resulting in significant effects on local fishing practices and their impact on resources. Fisher interviews were conducted in 2007 in this area to estimate fish catches, fishing yields and effort, to define a typology of informal fishing activities (including recreational, subsistence and benefit-aimed fishing), and to describe their spatial distribution. These results allowed the discussion of possible scenarios concerning the evolution of reef fish exploitation in a context of fast growing population and socio-economic changes. Local reef fisheries were essentially conducted through informal activities: 312 active boats were recorded and their catches reached 169 t/year whereas catches by professional fishers represented only 25 t/year with 4 boats. Practices and fishing yields were very diverse and linked to social, cultural and economic factors. Indigenous (Melanesian) fishers were mainly associated with subsistence and in some cases benefit-aimed activities (with informal commercialization), resulting in cost-benefit practices, important catches and the use of productive gears (gillnets). The fishers living in multi-cultural villages were mostly recreational, characterized by low yields and the use of less effective gears (spear gun, hand line). Fishing grounds were spatially structured according to these modern and traditional practices and their respective target biotopes. The main target families of reef fish were Lethrinidae, Acanthuridae and Mugilidae, the latter being mostly exploited by Melanesian fishers. The overall fishing pressure in the area (0.26 t/km^2/year) was low compared to other countries in the Pacific. However, its spatial distribution showed that some areas were lightly exploited whereas others were close to overfishing. Results showed that the expected rise in fish demand may lead to unsustainable exploitation levels in the latter zones. The increase in the recreational fishing fleet may also result in additional fishing pressure as well as reef degradations. From a social point of view, the fast economic development of the area is likely to disturb the present informal organization of fisheries and to initiate conflicts over the use of space and resources. Such perspectives call for urgent management measures. This case study therefore provided insights into the complex structure of informal fisheries in insular territories in the Pacific and their possible evolution when confronted with socio-economic changes.

1. Introduction

For many insular populations in the Pacific region, coral reefs represent a direct source of food, leisure and income (Moberg and Folke, 1999), but related small-scale fisheries are rarely integrated into institutional or commercial structured networks. Even if the inner rules that govern informal activities may vary from culture to culture (Lomnitz, 1988), informal fisheries can regroup any activity that is conducted without a license or outside any institutional framework. Informal fisheries thus encompass any kind of non-professional fishing, from recreational fishing (Cooke and Cowx, 2004; Lewin et al., 2006; Meyer, 2007; Zeller et al., 2008) to subsistence fishing (Dalzell et al., 1996; Kuster et al., 2005; Craig et al., 2008) or intensive benefit-aimed practices. These activities exist through a great variety of uses throughout the Pacific region, and are often tightly linked with local traditions, cultures and social networks (Ruddle, 1998; Preston, 2005). In some cases, the relation between people and resources is strengthened by customary marine tenures or traditional regulations (Adams, 1998; Johannes, 2002; Cinner, 2007), which often have beneficial effects on the status of exploited resources (Cinner et al., 2006, McClanahan

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et al., 2006). This link between fishing and socio-cultural diversity makes these activities notably vulnerable to socio-economic changes (Aswani, 2002; Cinner, 2005).

The changes in small-scale and traditional fisheries and their ecological impacts on marine resources as a result of demographic and economic growth is a major issue in fisheries science (King and Adeel, 2002; Hunt, 2003; Cinner et al., 2009). Modern socio-economic transformations have proved to influence the ability of local communities to use traditional or customary management, possibly threatening the status of natural resources and resulting in emerging governance issues (Hviding, 1998; Aswani, 1999; McIntyre and Foale, 2007). Levels of modernization or economic inequalities, distance to markets, population growth and dependence on marine resources were shown to be key factors of disturbance of traditionally managed resources (Cinner et al., 2007). More generally, the adaptation of rural or traditional fishers to the cash-based economy and the market demand highlighted the risks of jeopardizing a major source of income and food for the local populations, as well as the ecological integrity of the exploited ecosystems (Hviding, 1998; King and Adeel, 2002; Cinner et al., 2009). Such consequences have often been studied after modifications occurred, thus coping with already settled management issues or conflicts (Bellwood et al., 2004; Wilkinson et al., 2006). Yet, in a global context of demographic growth, comprehensive information is needed about informal fisheries to assess possible evolutions of marine resource exploitation and related impacts on socio-ecological systems. Nevertheless, despite their strong contribution to marine fishing pressure in most Pacific islands (Dalzell, 1996; Hunt, 1999; Hunt, 2003), informal reef fisheries have been poorly studied in regard to commercial and pelagic fisheries, and were generally underestimated because of data limitation (Polunin et al., 1996; Ruddle, 1998; Preston, 2005). Moreover, subsistence fisheries and recreational fisheries have frequently been studied separately in coastal environments although fishing grounds and target species may overlap (Kulbicki et al., 2000; Williams et al., 2008), making sectorial approaches unable to address entangled local management issues. Analyzing the structure and the functioning of the whole informal sector of fisheries would therefore be more appropriate in order to define management options and cope with the effect of major socio-economic changes.

The present work deals with such issues in a rural area of the north-west coast of New Caledonia, where an industrial mining project for nickel exploitation is currently being initiated. The oncoming economic development in this area is expected to result in new employment opportunities and a 100% increase in population density and urbanization in the next decade. First, this paper is aimed at characterizing the present structure of informal fisheries in this area, which is an important pre-requisite for discussing the possible consequences of socio-economic changes. Second, it is aimed at quantifying the resulting reef fish exploitation in order to identify possible risks of unsustainable exploitation in link with the observed complexity of local fisheries. To achieve these goals, fisher interviews were used to estimate fishing yields, efforts and catches (with spatially explicit representations), and to conduct a typology of informal fishers in this area. Finally, in order to examine whether the expected socio-economic changes would disturb local informal fisheries and in order to highlight key management issues, possible rises in fresh fish demand and in fishing pressure in the coming years were estimated.

2. Materials and methods

2.1. Study site

New Caledonia is a highly multi-cultural island, which results in a great variety of uses and fishing practices in its lagoon area. Apart from Noumea (capital city), where recreational fishing is predominant, rural areas show entangled cultures and complex fishing habits, defined simultaneously by Melanesian, Polynesian and European lifestyles (Leblic, 1999). The geographical settlements of these different communities, the local geomorphology and the diversity of reef fish resources (Kulbicki et al., 2000; Letourneur et al., 2000) have a strong influence on the structure of fisheries and their impact on resources. The study site was located on the north-west coast of the country (Fig. 1). The area was lightly populated: 9600 inhabitants were distributed across four multi-cultural and occidental-patterned villages (87%) and five Melanesian indigenous tribes (13%). Economic activities were dominated by agriculture, fishing and mine-related employment in the latter residential localities, whereas the tertiary sector was the most developed in Koné and Pouembout villages. The development of a metal-processing plant had recently boosted the urbanization in the surroundings of these two main localities, where about 6400 newcomers are expected to settle by 2015.

The 756 km^2 lagoon of the study area was delimited by an 83 km^2 mangrove and a 100 km barrier reef, located between 2.9 and 9.7 km from the shoreline (Fig. 1). New Caledonian institutions give public open access to the whole maritime zone but Melanesian customary claims have vigorously enforced a 61 km^2 exclusive fishing area in Oundjo tribe's surrounding waters (Fig. 1). In Melanesia, customary claims and marine tenures have often been associated with specific management plans and traditional fishing practices (e.g. periodic closures) (Cinner, 2007; Léopold et al., in press). However no customary rules were noticed in Oundjo's exclusive maritime area: the only consequence of this territorial claim on fishing activities was that outside fishers from neighboring tribes and villagers were not allowed to enter this zone. The rest of the study area was open to all, including fishers from Oundjo.

There was neither a marina nor a permanent mooring site in the study area, thus all boats had to be put in and taken out of water at one of the five public wharves for every trip (Fig. 1). The local fishing fleet was therefore composed of small to medium-size boats. Four professional fishers had been targeting reef fish in the survey area and exporting their catches to Noumea in the Southern Province. No legal fish market existed in the study area or its surroundings. Consequently the fresh fish commercialization network was not structured but relied on direct and parallel sales.

2.2. Sampling methods

Data were collected through interviews with local fishers using oriented questionnaires (Pollock et al., 1994). Outboard powered and unpowered boats were selected as the statistical units, because they were very likely to be linked to the most productive practices and the main part of the catches, as in other sites in New Caledonia (Léopold et al., 2004). Owners of such small fishing boats were part of most fishing trips and accurately aware of the fishing activities conducted with their boats. Thus only boat owners were surveyed to eliminate the risk of multiple counting of catches and effort data as fishing trips usually involved several people simultaneously. The sampling was stratified geographically: (1) boat owners from the four villages were sampled daily and randomly at each of the five public wharves during the three-month period between September and November 2007; (2) boat owners from the five tribes were almost exhaustively sampled at their home during the same period due to their low numbers in the study area. Information was collected on boat characteristics (length, year of registration) and the fishing activity of the boat in the year 2007 was described (average catches in kg per fishing trip, by target species and by gear; average number of fishing trips per month; detailed fishing areas by species and by gear using Landsat7 pictures at 1/130 000 scale; sale rate of catches). To address possible bias due to seasonal variations

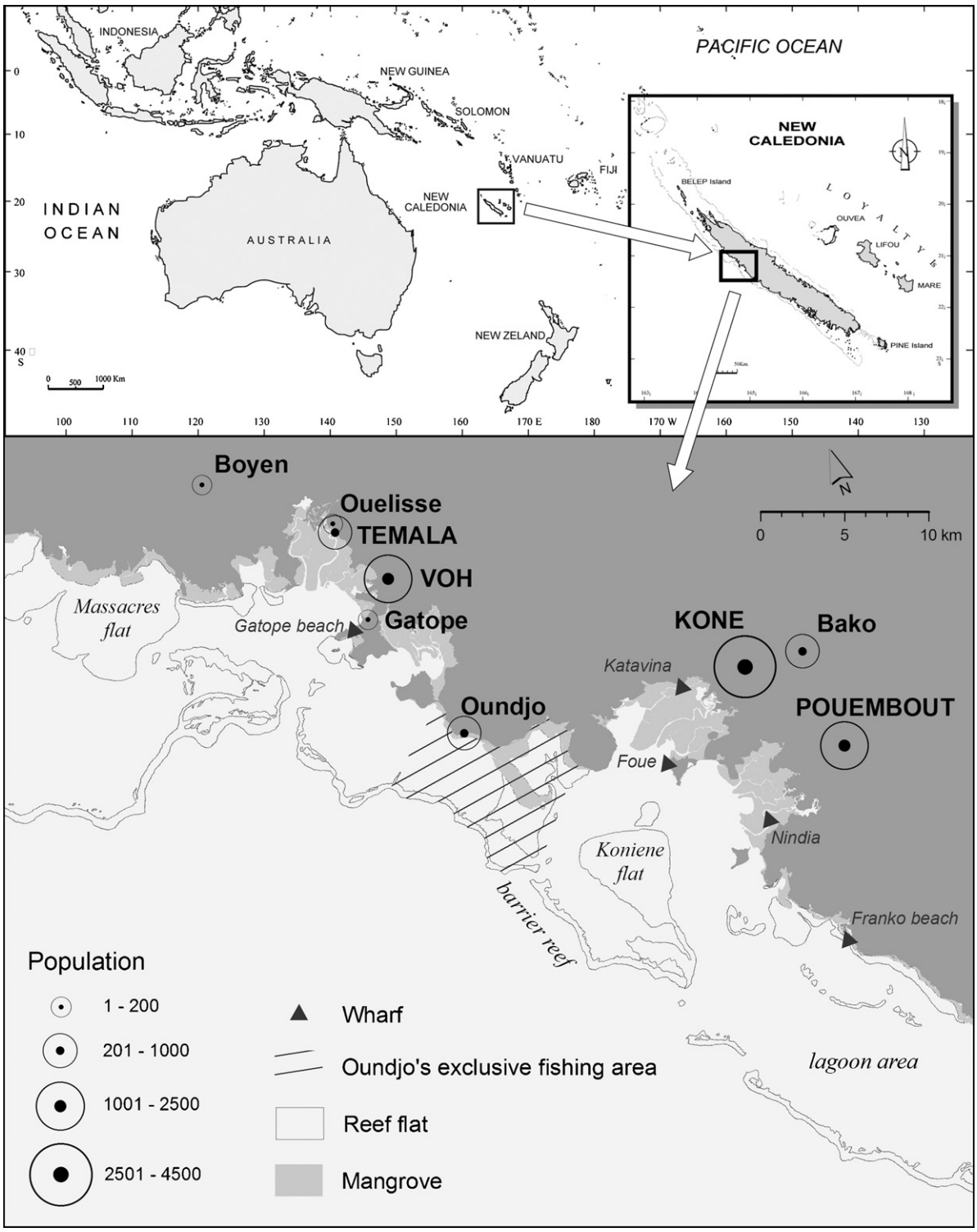

Fig. 1. Overview of the study area. The main reef flats and mangroves are represented. Villages: capital letters; tribes: lower-case letters.

of fishing activities, fishers were asked to describe their practices on a monthly basis during interviews. Data were then aggregated to provide yearly estimates.

2.3. Quantification of fishing activities

Boats were exhaustively and directly counted in the five tribes. Such a visual process could not be conducted in the four villages: the number of active boats was then estimated using the registration archives of the New Caledonia Marine Registration Office, which have recorded 645 boats since 1959 in the survey area. The effective size of the fleet in 2007 was smaller than the records indicated due to boats being destroyed over time. Therefore, these historical data had to be corrected using the interview results. Five four-year periods were defined between 1988 and 2007 and a sixth period grouped all the previous registration records. The number of active boats per village was then calculated using three length classes ($\leq$4 m; 4–5 m; >5 m) and considering two hypotheses: (1) 100% of

the boats registered since 2004 were still active in 2007; (2) the fishing effort of a given active boat in 2007 did not depend on its registration period. The sampling rate of boats at the wharves was thus only a function of their activity, whatever their age may be. Hypotheses (1) and (2) were validated with the sample data. The activity rate of boats was calculated for each stratum "registration period × length-class" considering all the villages (1). It was then used to calculate the number of active boats per village, from its respective number of registered boats (2).

$$R_{L,t} = \left(\frac{n_{L,t}}{N'_{L,t}}\right) \times \left(\frac{N'_{L,2004-2007}}{n_{L,2004-2007}}\right) \quad (1)$$

Then,

$$N_{L,v} = \sum_{t=1}^{6} N'_{L,t,v} \times R_{L,t} \quad (2)$$

where $R_{L,t}$ is the activity rate for boats of length-class L, registered during period t. It is assumed to be independent of the village considered. Hypothesis (1) gave $R_{L,\,2004-2007} = 1$. $N'_{L,t,v}$ is the number of registered boats of length-class L, registered during period t, in village v. $N'_{L,t}$ is the number of registered boats of length-class L, registered during period t, for all villages. $n_{L,t}$ is the number of sampled boats of length-class L, registered during period t. $N_{L,v}$ is the number of active boats of length-class L, in village v.

Catch values per sampled boat were calculated from the effort and yield values resulting from interview data (3).

$$C_{L,v,i} = F_{L,v,i} \times Y_{L,v,i} \quad (3)$$

where $C_{L,v,i}$ are the annual catches of boat i, from length-class L and village v. $F_{L,v,i}$ is the annual effort (number of fishing trips per year) of boat i, from length-class L and village v. $Y_{L,v,i}$ is the annual yield (catches per fishing trip) of boat i, from length-class L and village v.

Mean fishing effort, yield and catches in the sample were calculated using an *a posteriori* stratification "locality × length-class", and extrapolated using the $N_{L,v}$ values for these strata. Note that we assumed that discards of undesirable species or spoiled fish by fishers were very low. This assumption was based on previous observations of local practices that showed that gillnets were usually soaked for short periods of time and that most of the catches belonged to edible species. Extrapolated mean and total fishing efforts, yields and catches of the whole informal sector were then estimated using statistical inference formulas for a two-way stratification, along with respective variance and confidence intervals (Bryant et al., 1960). All the extrapolated results were detailed by target fish families, fishing gear and sale rate of catches.

Observations of boat activity were processed through a multiple correspondence analysis (SPAD® Software) of six active and three illustrative qualitative or semi-quantitative variables (Escofier and Pagès, 1998) (Table 1). A typology of fishing boats was built using a hierarchical classification which minimized intra-cluster variance (Ward, 1963). This typology was used to characterize different uses of reef fish resources, thus discriminating various types of fishers according to their fishing habits and socio-economic background (Pelletier and Ferraris, 2000).

2.4. Spatial analysis of fishing data

Individual fisher maps and related information on catches were digitized in a geographical information system (ESRI ArcGIS®). The distance between the barycentre of each fishing zone and the wharf of departure was measured. It was assumed that the zones identified during interviews were spatially representative of the zones that were effectively visited by all fishers. For each fishing zone, the ratio between the local catches and the total catches observed in the respective "locality × boat length-class" sampling stratum was calculated. This ratio (i.e. the proportion of the zone in the stratum in terms of annual catches) was then used to proportionally distribute the total estimated catches of the stratum between the different zones, thus providing extrapolated catch values for each fishing zone. These results were compiled and mapped using a grid of hexagonal pixels (Tirunelveli et al., 2002). Each pixel had a width of 500 m (i.e. a surface of ~21.6 ha). This level of accuracy was based on the estimated accuracy while drawing fishing areas during interviews. In the process, the catch value of each fishing zone was attributed to respective pixels proportionally to the surface of the zone that intersected these pixels, in order to avoid overestimation. Finally catch values on each pixel were added to compile all individual maps.

Table 1
List of the variables and modalities used in the multiple correspondence analysis and the hierarchical classification of fishing activities in the study area.

	Variables	Number of modalities	Detailed modalities
Active variables	Boat length (m)	3	<4; 4–5; >5
	Main fishing area	3	Lagoon/mangrove only, lagoon/mangrove and barrier reef, barrier reef only
	Annual fishing effort (number of fishing trips)	3	<12; 12–24; >24
	Fishing yield (kg/fishing trip)	3	<10; 10–25; >25
	Annual catch (kg)	3	<200; 200–700; >700
	Main gear	4	Spear gun, gillnet, handline
Illustrative variables	Locality	9	Bako, Boyen, Gatope, Koné, Oundjo, Pouembout, Témala, Ouélisse, Voh
	Type of locality	2	Village, tribe
	Sale rate of catch	3	<10%; 10–50%; >50%

3. Results

3.1. Fishing effort and catch data

A total of 146 interviews were fully useable for analyses. We estimated that 312 fishing boats were active in the area. According to these estimates, 47% of the total number of active boats was sampled (94% of the active boats in tribes and 37% in villages). The total catches of reef fish by informal fishers and total effort were estimated respectively at 169 t/year and 7720 trips/year in the area (Table 2). The mean yield, effort and catches per boat are given in Table 2.

The distribution of fishing boats between tribes and villages was very heterogeneous: 17% (52 boats) was owned by Melanesian fishers and 83% (260 boats) by fishers from villages (hereafter

Table 2
Annual mean (per boat) and total catches, efforts and yields for informal fisheries in the study area.

	Per boat			Fleet		
	Mean	SD[a]	CI[b]	Total	SD[a]	CI[b]
Catch (t/year)	0.70	*0.08*	*±0.16*	169	*4*	*±8*
Effort (number of fishing trips/year)	31	*3*	*±5*	7720	*240*	*±460*
Yield (kg/fishing trip/boat)	23	*2*	*±4*	–	–	–

[a] Standard deviation.
[b] 95% confidence interval.

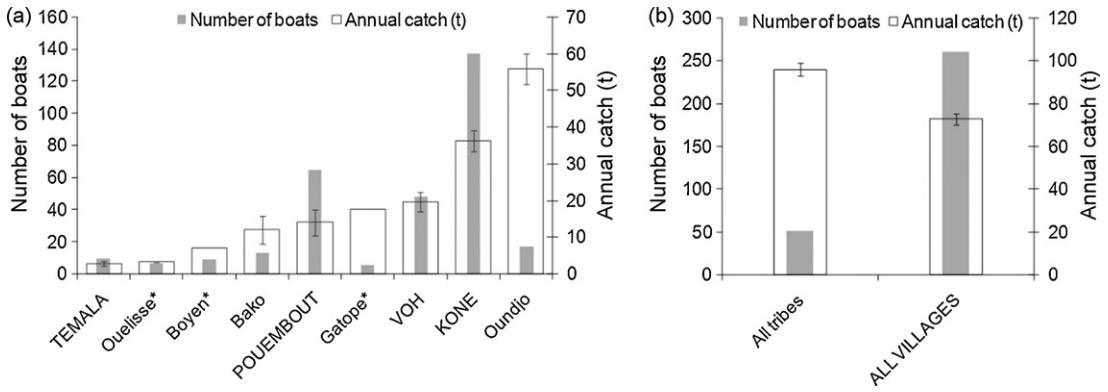

Fig. 2. Annual catch (t), number of active fishing boats per locality (a) and type of locality (b). The error bars indicate 95% confidence intervals of catch estimates. Localities marked with a "*" were exhaustively sampled. Villages: capital letters; tribes: lower-case letters.

called rural fishers) (Fig. 2a). However, the annual fishing effort reached 3150 trips/year in tribes (41% of the total effort) and 4570 trips/year in villages (59%). The total of annual catches was very variable between localities (Fig. 2b). Large villages (Koné, Pouembout and Voh) showed medium to high levels of annual catches but paradoxically the major part of the catches was made in tribes (93 t *versus* 73 t in villages). This was mainly due to the Oundjo tribe, which represented respectively 58% and 33% of the catches for all tribes and for the whole area, and only 21% of the total fishing effort in the area. The distribution of the annual catches among reef fish families showed rather similar patterns in tribes and villages. Lethrinidae was the most targeted fish family (42 t per year in the whole area), followed by Acanthuridae, Mugilidae, Scaridae, Serranidae and Siganidae (Fig. 3). The main difference in the top-ranked target families came from Mugilidae, which were much more prized by Melanesian fishers than rural fishers (respectively 17 t/year and 4 t/year). Carangidae also showed higher levels of catches in tribes (6 t *versus* 1 t in villages). By comparison, four fishing licenses were delivered in 2007 for coral reef fish, and respective catches only reached 25 t. They were mainly composed of Mugilidae (83%), then Lethrinidae (4%), Acanthuridae (4%) and Scaridae (2%).

3.2. Typology of fishing activities

The main factorial plane explained 31.1% of the variability between observation units. Axis 1 was mainly determined by "Annual catch" and "Fishing yield" (respectively 35.1% and 30.3% of the total inertia). In particular, it significantly discriminated tribes and villages. Axis 2 was mainly determined by "Annual fishing effort" and "Main gear" (respectively 29.3% and 17.4% of the total inertia). The "Boat length" and the intensity of fishing activities (i.e. "Annual catch", "Fishing yield" and "Annual fishing effort") formed two gradients of similar shapes but antagonist directions on the main plane (Fig. 4a). The level of fish commercialization spread on another gradient. The directions of these three gradients suggested that the small boats made the highest catches (along with the highest fishing yields and effort), and were related to higher sale rates.

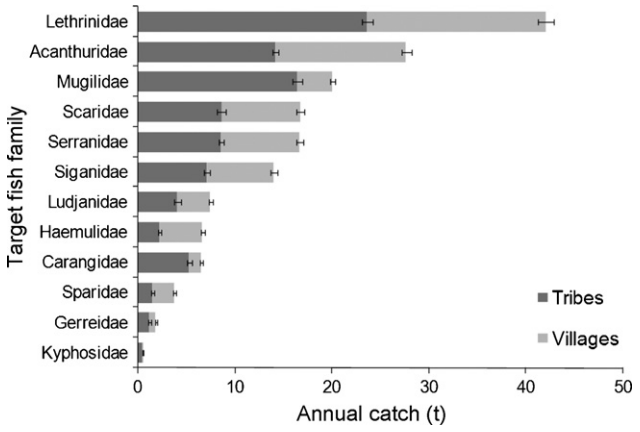

Fig. 3. Total annual catch (t) for the main target families of reef fish, for tribes and villages. Confidence intervals (95%) for catch estimates are indicated.

The Oundjo and Gatope tribes were associated with the highest values of catches, yield, effort and sale rates, thus being strongly discriminated from other localities by axis 2. According to the information from the interviews, the sold catches were commercialized locally outside any formal network. In general, these results markedly opposed villages and tribes, the latter being characterized by more intensive fishing activities and a shorter boat length. The distribution of "Main gear" also showed that rural fishers have a greater use of the hand line and spear gun than in tribes, where gillnet was the predominant gear. This was linked to the location of the main fishing areas close to the barrier reef and in the inner lagoon, respectively (Fig. 4a). Three clusters of boat types and activities were defined (Fig. 4b), showing that different patterns of informal fishing practices were coexisting in the study area (Fig. 5).

The first cluster was significantly characterized by (1) high values of annual catches, effort and mean yield, (2) small boats and shore fishing (particularly in mangrove areas), (3) the use of highly effective but poorly selective gear (mainly gillnets), (4) income-generating practices and (5) tribal localities (80% of units, in particular in Oundjo and Gatope). The interviews highlighted that fishers from this category were likely to fish throughout the week. This rather intensive fishing practice required technical skills and a good knowledge of the local marine environment, and often aimed at maximizing trip productivity. This professional-like activity was actually driven by income and food needs, thus resulting in more intense exploitation than subsistence fishing alone.

On the contrary, the second cluster was typical of pure recreational fishing that preferably occurred during weekends and holidays rather than during regular weekdays. Of the boats in this group, 96% were registered in villages (mainly Koné and Pouembout). Practices were characterized by (1) low levels of annual catches, effort and mean yield, (2) large boats and reef fishing, (3) hand line and (4) no sale.

The third cluster grouped boats of the most rural villages (Voh and Temala) and inland tribes (Bako and Boyen). The mean size of boats (4.5 m) and trip frequency showed the same patterns as in cluster 2: effort was low (~20 trips/year) and was mainly dis-

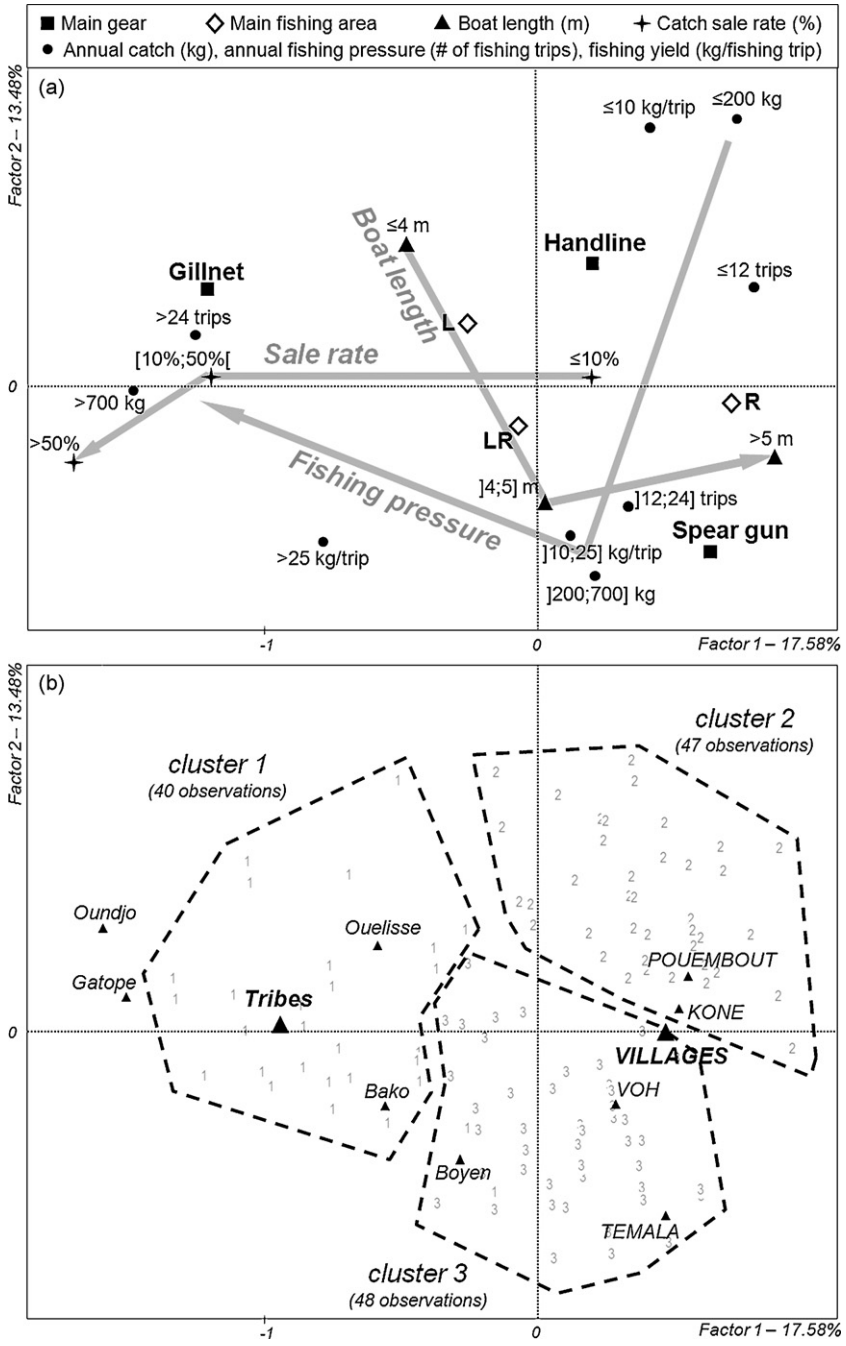

Fig. 4. (a) Main factorial plane of the multiple correspondence analysis: projection of modalities for the active variables (see Table 1 for details) and for the illustrative variable "Sale rate of catch". Schematic gradients illustrate the distribution of modalities. Modalities for *Main fishing area*: "L": lagoon/mangrove only; "LR": lagoon/mangrove and barrier reef; "R": barrier reef only. (b) Projection of observations in the main factorial plane, and modalities for illustrative variables concerning localities. Schematic clusters from the hierarchical classification are represented. Villages: capital letters; tribes: lower-case letters.

tributed during non-working days. However, annual catches, mean yield and spear gun use were slightly higher than in cluster 2. These were therefore interpreted as characteristics of both recreational and subsistence fishing.

3.3. Spatial distribution of fishing grounds and catches

The mean distance covered during a fishing trip was measured from individual fisher maps. It was twice as high in villages (10.4 km, SD *7.4*) as in tribes (5.7 km, SD *3.8*). This was consistent with the results of the cluster analysis, which showed that rural fishers tended to visit areas further away (especially the barrier reef) than Melanesian fishers. The latter were more likely to visit fringing reefs, mangroves and the inner barrier reefs that were close to the shore (Fig. 6). The location of fishing grounds showed a clear sectoring depending on the residence of fishers. Oundjo's exclusive fishing area was well respected by other fishers, thus separating the study area into two distinct zones that were exploited by boats coming from the southern and the northern localities, respectively. This geographical segregation resulted in a low overlap of fishing areas between the northern and southern zones.

Our catch estimates corresponded to a mean fishing pressure of 0.24 t/km^2/year in the study area. However, fishing pressure was heterogeneously distributed, mostly focusing on reef flats and man-

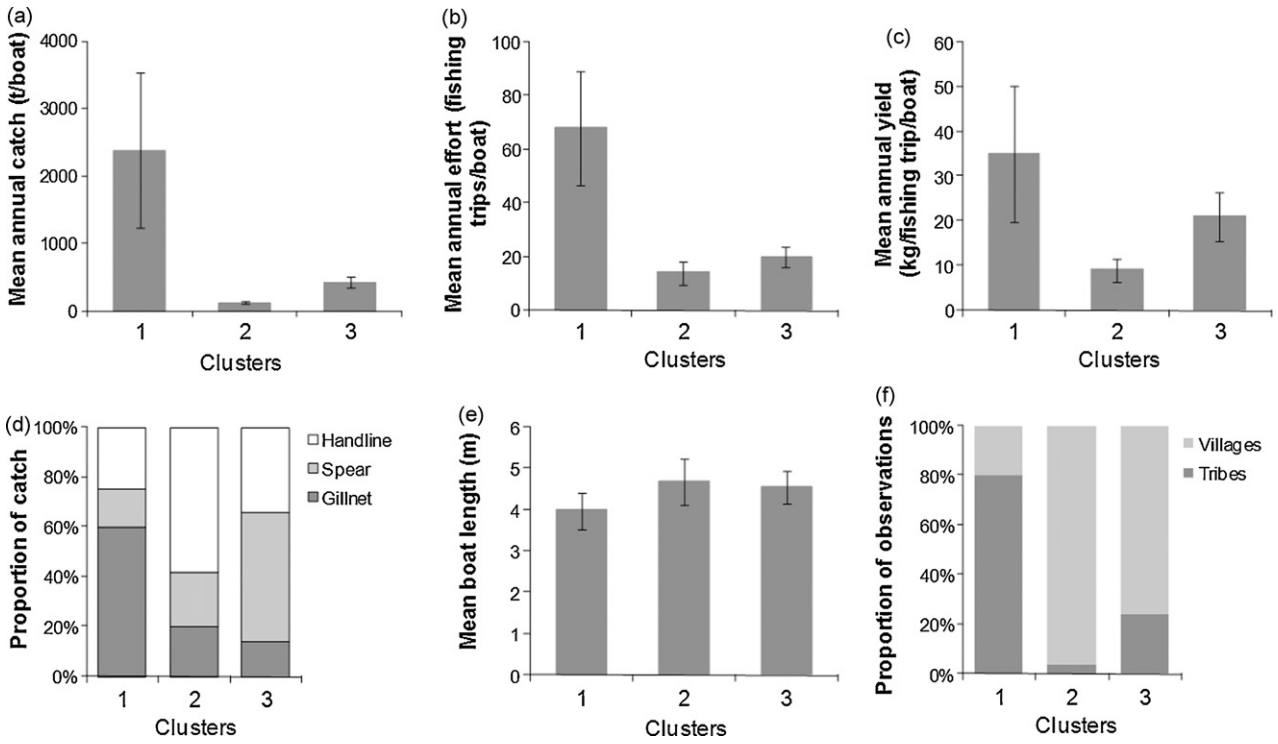

Fig. 5. Characteristics of the three clusters (following multiple correspondence analysis, see Fig. 4), regarding: (a) mean annual catch per boat; (b) mean annual fishing effort per boat; (c) mean annual yield per boat; (d) proportion of catch per type of gear; (e) mean boat length; (f) proportion of observations per type of locality (villages/tribes). The error bars represent standard deviation for the mean.

grove borders (Fig. 7). The major part of the area was lightly fished with regard to the conservative 1 t/km^2/year threshold for sustainable reef fisheries (Newton et al., 2007). However in ~3% (~21 km^2) of fishing grounds, catches ranged between 1 and 5 t/km^2/year, the latter value defining the reference threshold of unsustainable reef fisheries (Newton et al., 2007). This situation mainly occurred (1) alongside the barrier back reef, the mangrove and the fringing reef areas inside Oundjo's exclusive fishing area and (2) alongside large estuarine mangrove areas located close to Voh and Koné villages.

3.4. Projections of fish demand and fishing pressure

Oncoming changes in fresh fish demand were estimated from fishing data and expected demographic increase. The economic

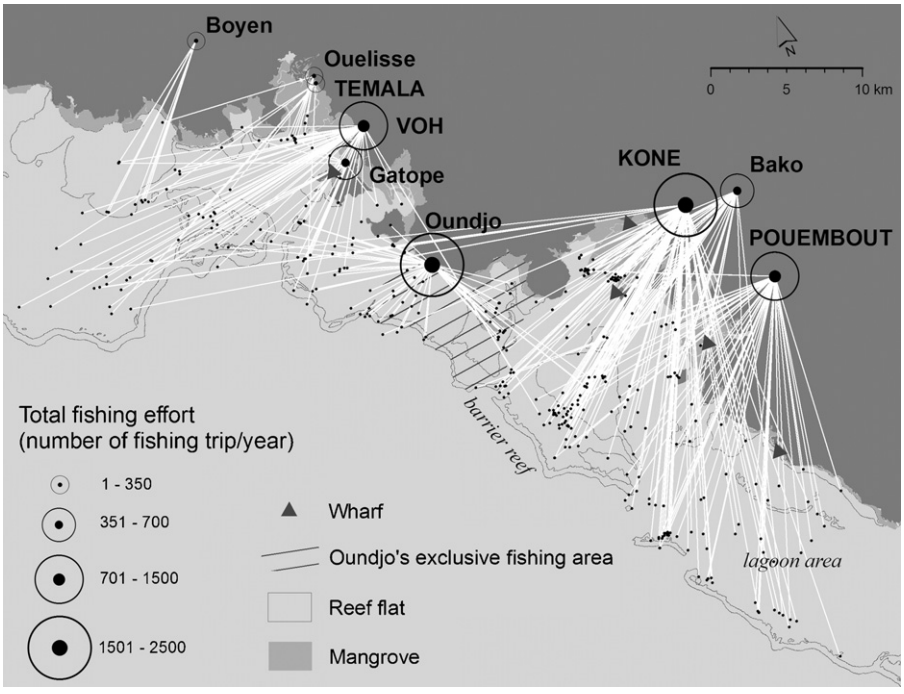

Fig. 6. Annual fishing effort per locality, and spatial distribution of fishing grounds in relation to locality (from sample data). The white threads show the link between the barycentre of fishing areas and the locality inhabited by fishers. Villages: capital letters; tribes: lower-case letters.

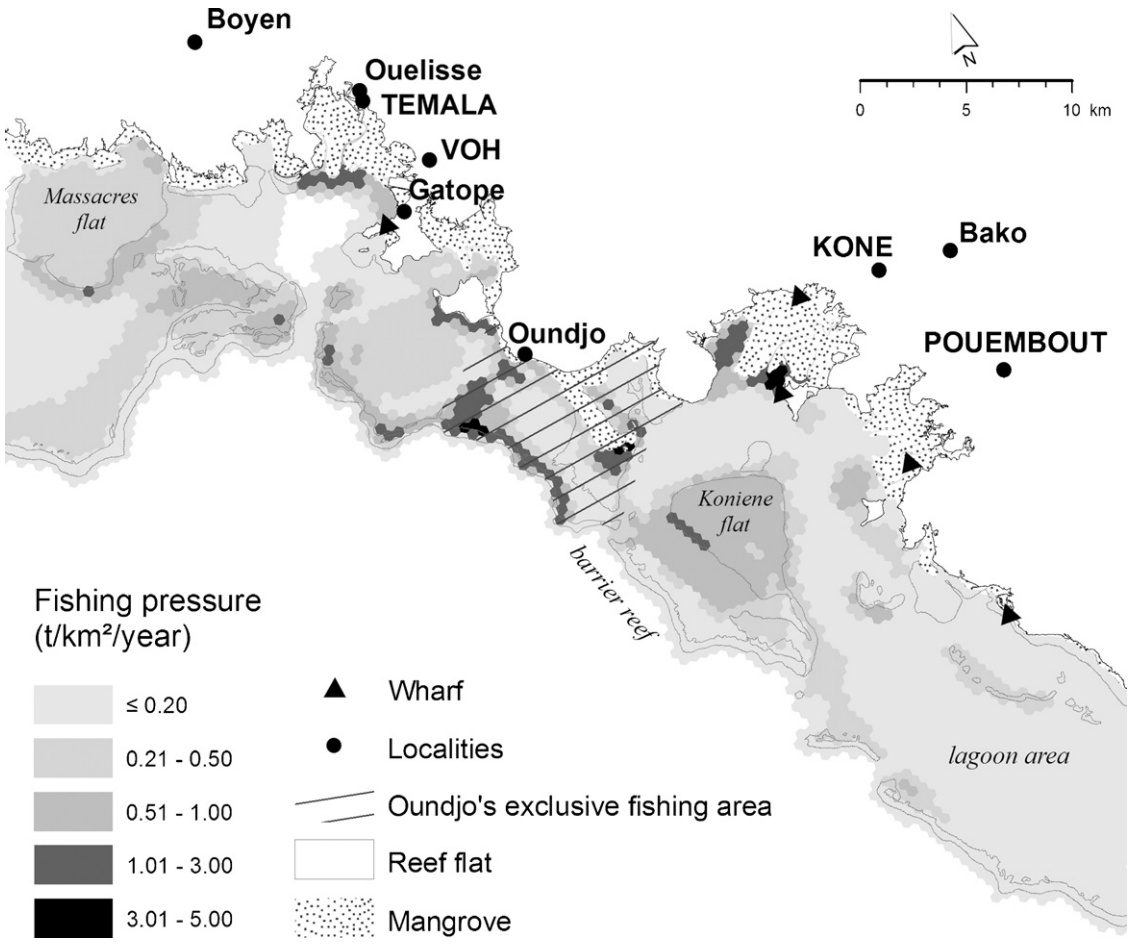

Fig. 7. Spatial representation of fishing pressure (in t/km^2/year) in 2007 in the study area. Shades of light gray indicate levels of fishing pressure lower than 1 t/km^2/year, shades of dark gray indicate levels of fishing pressure above 1 t/km^2/year. Villages: capital letters; tribes: lower-case letters.

development of the study area is expected to create large employment opportunities for local people and thousands of newcomers. The population in Koné, Voh and Pouembout is expected to increase respectively by 3300 (+62%), 1900 (+76%) and 1200 (+74%) inhabitants toward 2015. Given the estimated informal catches (169 t/year) and the local population (9600 inhabitants) in 2007, the annual reef fish consumption was estimated as 18 kg/capita/year in the study area. This was consistent with previous data giving a slightly higher value at the national level (23 kg/capita/year) including outer-shelf pelagic species and imported fish (Labrosse et al., 2000). Given the expected 67% increase in the population and assuming a steady state of reef fish consumption toward 2015, the local demand for fresh reef fish products would rise by approximately 110 t/year.

Newcomers are likely to settle in the main villages and join the recreational fishing sector given their expected socio-professional category. Assuming that the ratio of fishers inside villages remains constant over this period, our results suggested a 54% and a 13% increase in the number of recreational boats (+ 170) and catches (+ 22 t/year), respectively. Lethrinidae, Acanthuridae, Scaridae and Serranidae would probably be the main families sensitive to this rise in recreational fishing. Moreover, such a significant increase in the utilization of lagoon waters by recreational boats from Koné and Pouembout villages in the Southern area is likely to (1) raise territorial conflicts with Oundjo's fishers at the Southern border of their informal exclusive area, and (2) induce damage to the most visited reefs (mainly barrier reefs) through repetitive boat anchoring, trampling or snorkeling (Liddle and Kay, 1987; Harriot et al., 1997; Backhurst and Cole, 2000).

However, a significant 88 t/year of emerging demand for fresh fish would not be addressed directly by these newcomers. Two scenarios were thus considered.

The most pessimistic scenario for local fish resources would happen if the whole emerging demand were addressed locally, through the development of the informal and/or legal market. This would boost benefit-aimed activities of informal and professional fishers. In this case, the additional 110 t/year catches would represent a 65% increase with regard to the present 169 t/year. Such a trend would generate an additional fishing pressure of 0.15 t/km^2/year yield at the scale of the whole study area, but is likely to affect the lagoon area heterogeneously. In particular, it may concentrate in the main present fishing grounds, namely the border of estuarine mangroves, reefs in Oundjo's exclusive area, Koniene flat and large sections of the barrier back (Fig. 7).

The second scenario assumes that the emerging fish demand is not predominantly supplied locally. Indeed the socio-economic context in New Caledonia provided historical evidence of antagonist effects of the mining industry on commercial fishing activities (Conand, 1987). The employment perspectives for low qualified workers turned the Melanesian fishers away from the exploitation of trochus and sea cucumbers during the nickel boom of the 1960s. Similar factors may make this scenario occur again on the Northwest coast of the country in the coming years. Part of the additional demand for fish may then be addressed through imports of fresh or frozen fish or meat products. Therefore the increase in fishing

Table 3
Comparison of the fishing pressure on coral reef fish resources of several Pacific islands.

Country	Fishing pressure (t/km^2/year)	Reference
New Caledonia		
Ouvea atoll	0.25	Léopold et al., 2004
Northern Province	0.17	Labrosse et al., 2006
Northwest coast	0.26	this study
Tonga islands		
Lofanga	0.5–3	Kronen and Bender, 2007
French Polynesia		
Tikehau atoll	0.3	Kronen et al., 2006
Fiji	0.3–10.2	Dalzell, 1996
Niue	9.3	Dalzell, 1996
Nauru	4.5	Dalzell, 1996

pressure in the study area would not be as high as in the first scenario, and the customary claim on Oundjo's lagoon area might then provide protection against outside recreational fishers on the long term.

4. Discussion

4.1. Informal fisheries: diversity of practices and risks of unsustainability

Our results support previous studies showing that exploitation levels of coastal marine resources by informal fishing (such as subsistence or recreational fishing) in Pacific islands often exceeded those by professional fishing (Dalzell et al., 1996; Hunt, 2003; Schumann and Macinko, 2007). The exploitation of commercially important species was indeed driven by informal fishers (87% of the annual catches) and about 22 t (13%) of their catches was estimated to be sold off in the local parallel market, which may compete with the catches by professional fishing (25 t in 2007).

This study also emphasized the great diversity of practices and exploitation levels characterizing informal fisheries, as it was already reported in the Pacific (Ruddle, 1998; Labrosse et al., 2006; Lunn and Dearden, 2006). This complex structure was linked to the socio-cultural and economic background of fishers who have woven varying relationships with marine resources and the environment: the lagoon area appeared to be a source of income or complementary proteins, as well as the field of recreational and occasional uses. Similar observations were made at the scale of the Northern Province of New Caledonia using household consumption surveys (Labrosse et al., 2006). These authors found that factors such as the ethnic community and the geographical location partly explained consumption habits and thus fishing behaviors. In our case study, two tribes among the nine localities considered (Oundjo and Gatope, 5% of the total population) represented 57% (96 t/year) of the total annual catches. This was related to a few highly productive fishers whose catches were dedicated to both self-consumption and income. On the other hand, 83% of informal fishing boats were located in multi-cultural villages and were most often used for recreational purposes. This resulted in a high utilization of lagoon waters by recreational boats (62% of fishing trips), although they exerted a relatively low fishing pressure on resources.

The fishing pressure due to informal fisheries in the study area was estimated at 0.24 t/km^2/year (0.26 t/km^2/year when including catches by professional fishers). This was lower than the estimated fishing pressure on coral reef ecosystems in other Pacific countries (Table 3). However, it was 35% higher than the average fishing pressure in the lagoons of the whole Northern Province, although the catch composition for Melanesian fishers was similar (Labrosse et al., 2006). The stronger exploitation levels in our survey area may therefore result from the higher population density and a higher urbanization rate. Worldwide, fishing pressure on reefs ranges from 0.2 to 40 t/km^2/year with a median of 3 t/km^2/year and a maximum sustainable yield (MSY) estimated at about 5 t/km^2/year (Newton et al., 2007). This generic reference value is likely to vary between regions depending on a range of factors that drive the fisheries productivity (e.g. island size, reef area, species richness). Indeed, Labrosse et al. (2000) estimated local MSYs for multi-specific reef fisheries in different sites in New Caledonia: they reached 4 t/km^2/year and 2.77 t/km^2/year in Voh and Koné sectors (including Oundjo) respectively. These estimates were consistent with the previous thresholds (Newton et al., 2007) and suggested that the MSY in the study area probably ranged between 1 and 5 t/km^2/year. We thus considered that such a range of fishing pressure would correspond to a risk of unsustainable fishing.

At the scale of the whole study area, fishing pressure was far below conservative thresholds (0.26 t/km^2/year), which would support the view that local fisheries have a significant development potential. However, its spatial distribution showed that some specific zones, totaling ~3% of the total extent of fishing grounds, were more heavily exploited and close to MSY thresholds. This provided evidence that over-exploitation may occur by pockets even at a small scale (here a few square kilometers), which is likely to be unnoticed when considering large scale estimates (Cinner and McClanahan, 2006).

This heterogeneous spatial distribution of fishing pressure was driven by the diversity of fishing practices existing in the area. Indeed, distant barrier reef areas such as Koniene flat and Voh barrier back reef were lightly targeted (< 1 t/km^2/year) and mainly constituted recreational fishing grounds. The most heavily exploited patches were located alongside mangrove areas, and more surprisingly, inside Oundjo's customary area despite its exclusive control over resources. This may be explained by the extent of the tribe's fishing grounds (the lagoon being smaller in this area), the high dependence of Oundjo's fishers on marine resources for cash income, and the absence of customary rules to mitigate fishing, among other factors. These geographical, socio-economic, and cultural drivers may have partly counteracted the potential of this area to regulate fishing pressure by limiting outside boat access. In this respect, Oundjo's area represented an original case of customary marine tenure in Oceania, where traditional management was often linked with beneficial effects on resources (Cinner et al., 2005).

4.2. Informal fisheries confronted with socio-economic changes and management perspectives

The above considerations stressed that fishing pressure on reef fish resources in this study area was driven by population socio-economics, especially through recreational activities, fish consumption and trade, and cultural aspects, as it was already reported in other studies (Aswani, 2005; Cinner and McClanahan, 2006; Cinner et al., 2007). The spatial and quantitative assessment of informal fishing allowed discussing the possible consequences of socio-economic changes on local fisheries and resources. These results underlined the necessity to understand the structure and complexity of informal fisheries, and highlighted key management issues. Two scenarios were based on different hypothesis of fish supply in the coming years. How the growing demand in fish products would be addressed actually constitutes both the main uncertainty and risk for local resources in the next decade. This issue advocates for the implementation of long-term catch surveys and interview campaigns among local fishers to monitor the evolution of practices (Ainsworth and Pitcher, 2005). Such data would help assessing which of the two scenarios is more likely to occur and thus allow adapting local management measures for the conservation of exploited resources. In parallel, the probable increase in the

number of recreational boats calls for measures that would help in the management of an increasing recreational fleet (e.g. installation of permanent mooring structures in the most visited sites).

Moreover, such changes in informal fisheries may also have social consequences in addition to ecological issues. Indeed local fisheries were an assemblage of traditional, recreational, subsistence and benefit-aimed fishing practices, which referred to varying perceptions and objectives. Conflicts between such different fishers have highlighted the necessity to define adequately the rights and responsibilities of all resources users (Bennett et al., 2001) in Australia and New Zealand (Kearney, 2001), Kenya (McClanahan et al., 2005) or more generally in Southeast Asia (Pomeroy et al., 2007). In the present case, antagonist and overlapping fishing uses raise potential risks of conflicts in a context of a fast growing population and strong immigration. In particular, the significant number of recreational power boats operating in the lagoon waters compared with the few Melanesian fishing boats may enhance territorial claims, although fishers' typology suggested that the most important overexploitation risks are likely to come from the already settled population rather than from newcomers. The latter would possibly be the trigger of such a phenomenon by generating additional demand and catches but may not be the major actors of a significant increase in fishing pressure on local reef fish resources (at least on the short-term). In this respect, taking into account the present zoning of the lagoon area, especially the Oundjo's exclusive fishing area and the related customary claims, is of primary importance. Co-management strategies and preventive measures should be promoted to tackle such an issue (Olsson et al., 2004). Relevant management options should be discussed through collaborative management between public authorities and modern and traditional users, integrating the spatial organization of fishing activities and the various perceptions of the stakeholders involved (Kearney, 2002; Verheij et al., 2004).

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