Geographical aspects of informal reef fishery systems in New Caledonia


ABSTRACT

The coral reefs in New Caledonia have long been used by the local population for subsistence as well as commercial and recreational purposes. The impact of informal fisheries on reef ecosystems illustrated the idiosyncrasies of New Caledonian fisheries in the southwest Pacific. This paper compared informal fishery systems on the southwest coast (close to the capital and economic center of the country) and the northwest coast (where an industrial mining complex has been under development) of New Caledonia to analyze their spatial structure and characteristics. Four geosystems were defined. These depended on the natural, social and economical environments as well as management strategies. The way of life of the local population who develop sustainable fisheries (Dalzell and Adams, 1997). For example, the protein provided by a small commercial fishery in Vanuatu in the mid 1980s was estimated to be 13 times the protein provided by a small subsistence fishery. This study suggested that ongoing socio-economic changes in New Caledonia have shaped informal fishing activities since the 1900s. The findings from this study validate the suitability of spatial approaches to coral reef fisheries and provide local stakeholders with original management clues for marine resources sustainability.

1. Introduction

Many previous investigations dealing with the characterization of fisheries did not take into account the spatial distribution of fishing practices and catches (Caddy, 1996). They were often based on numerical models in which spatial variations were missing because study areas were considered homogenous (Booth, 2000). However, all marine ecosystems are spatially heterogeneous (Babcock et al., 2005). Throughout the Pacific Ocean, highly diverse coral reef ecosystems (Mora et al., 2003) have long been used by the local population who develop sustainable fisheries (Dalzell and Adams, 1997). Their fishing practices and organization evolved alongside European expansion in the 19th century (Dalzell, 1998). Most local societies progressively entered a monetary system, which led to the coexistence of several types of coastal fisheries: subsistence, commercial and recreational (Conand, 1987; Leblic, 1988; Jollit-Boniface, 2007).

Like other Pacific islands, coastal fisheries in New Caledonia have an informal sector (Dalzell and Adams, 1997). In this paper, the term 'informal fisheries' encompasses all fisheries that do not require a fishing license. This includes:

(1) Subsistence fishing: the activity of local and non-commercial fisheries, primarily focused on providing fishers, their families and the community with food (Berkes, 1990).
(2) Commercial practices within a parallel market: economic activities or systems sustaining a basic level of livelihood but no profit. Profit is understood as no limit to wealth or its acquisition (Schumm and Macinko, 2007).
(3) Recreational fisheries: all fishing activities that do not lead to commercial fish sales.

In these cases, commercial sport fishing like chartering can be considered. Hence, fishery resources can provide fishers and businesses with goods and services (Beckley et al., 2008; Pawson et al., 2008).

Informal fisheries are generally difficult to characterize due to their geographical dispersion, the variable intensity of their activities and the lack of awareness of the status of fishers in changing societies (Cillaurren and David, 2000). However, compared with commercial fisheries in many other Pacific islands, they are believed to be highly productive and diversified and contribute to the food security of coastal communities (Dalzell and Adams, 1997). For example, the protein provided by a small commercial fishery in Vanuatu in the mid 1980s was estimated to be 13 times lower than that supplied by the informal village fisheries (David, 2008).
Today these figures seem to be still accurate in rural areas, especially in places where the market economy remains very weak.

The situation is similar in New Caledonia (Leblic and Teulière, 1987; Daguzan, 1994; Jollit-Boniface, 2007) where informal fisheries’ catches are assumed to be much greater than professional landings, although the community of fishers is heterogeneous and poorly studied. In this context, the lack of knowledge and data on these fisheries in a society facing profound changes, made any kind of assessment to be considered with caution. Local authorities have therefore expressed growing interest in research regarding the sustainable management of local marine resources. New Caledonian cultural, socio-economic, environmental and institutional context makes research on this issue valuable (David et al., 2010). New Caledonian socio-cultural communities have been shaped by the newcomers who settled on the archipelago through successive waves of immigration since the 1880s. European settlers, Asian and Polynesian workers had varying relationships with native Melanesians. Nowadays, 28% of Melanesians reside in tribes (INSEE, 1997), while the rest lives in villages or in the town Nouméa. In this paper, tribes are considered the traditional social and spatial organization relative to the Melanesian–Kanak culture (Guillaud, 1996; Bensa and Leblic, 2000).

The aims of this paper were (1) to describe the informal fishing fleet (who are the fishers? how many are they?); (2) to characterize and analyze the complexity of the informal fisheries and their causes (why do fishers have different fishing practices?); (3) to estimate the impacts of informal fisheries on the coral reef ecosystems (in terms of fishing pressure, targeted habitats); (4) to identify the factors that structure the spatial distribution of fishing activities; (5) to determine to what extent the analysis of the fishery systems and the understanding of their diversity can facilitate a prospective management analysis.

In order to address these questions, a spatial and systemic approach was conducted in two socio-economically contrasted sites on the west coast of New Caledonia. Surveys were designed and conducted among informal fishers to gather spatially explicit and quantitative data on their regular activities (Pollock et al., 1994). Statistical and spatial analyzes were undertaken to estimate fishing catches, efforts and yields, and to characterize and map informal fishing practices through a geographic information system (GIS). This descriptive approach allowed different types of fishery ecosystems to be defined (Corlay et al., 1995; Bertrand and Bertrand, 2000). These classifications were then discussed to suggest management strategies at large spatial and temporal scales in regard to the economic and urbanization growth that New Caledonia has to face in the next decades with the development of the mining industry.

2. Materials and methods

2.1. Study areas

New Caledonia is located in the Melanesian cultural area (Fig. 1). The reef-lagoon ecosystems encompass a significant level of biodiversity based on a large variety of habitats (127 geomorphologic reef units according to Andréfouët and Torres-Pulliza (2004), Table 1). The fish resources, in particular, constitute an extensive biomass together with a high diversity of species (Kulbicki et al., 2000; Chabanet et al., 2010). Some of these ecosystems were added to the UNESCO’s World Heritage list in 2008 (David et al., 2010).

The present study focuses on two research areas located in the northern (1) and the southern (2) Provinces of the country (Fig. 1).

2.1.1. The Voh-Koné-Pouembout (VKP) lagoon site

The northern study site is lightly populated. Of its 9600 inhabitants, 87% live in four rural multicultural villages where the tertiary sector is most developed (Fig. 2). In contrast, the economic activities of the five traditional Melanesian tribes, which represent the remaining 13% of the population, focus on the primary sector and have been affected by rising mine-related employment. As a result of the settlement of an industrial mining complex, the two main localities, Koné and Pouembout, are changing through intensive urbanization and development. Several thousand newcomers are expected to settle here by 2015.

The area comprises a 756 km² shallow lagoon (with a depth between 5 and 17 m), bordered by 83 km² of mangrove and delimited by a 100 km barrier reef. This barrier reef is located between 2.9

Fig. 1. New Caledonia in the southwest Pacific region; and location of both study areas. Areas 1 and 2 represent the study areas in the northern and southern Province respectively. All maps in this article correspond to the areas 1 or 2.

and 9.7 km from the shoreline, which is much closer to shore than in the southern site.

There is no marina or permanent mooring zone within this area, meaning all fishing boats must use available public wharfs. Under French law, the access to the sea water must remain free to all, although the coastal Oundjo tribe claims for a 61 km² exclusive fishing area that is actively enforced for customary reasons.

2.1.2. The southwest (SW) lagoon site

The second site includes Nouméa, the capital (92,000 inhabitants) and economic center of New Caledonia, along with four peri-urban villages (59,000 inhabitants), namely Païta, Mont Dore, Dumbéa and Boulouparis (Fig. 2). Here, the dominant cultural group is European, mostly from France (ITSEE, 1996). The Melanesian, Polynesian and Asian communities constitute a higher proportion of the population in the villages surrounding Nouméa. The economic system involves traditional occupations and small- and medium-sized enterprises and industries. A rural way of life predominates beyond these suburbs. Settlement is grouped and organized in either Melanesian tribes or large multicultural villages. The main economic activities are agriculture and services. The inhabitants living in Melanesian tribes represent only 2.2% of the total population and as such were not included in the survey.

The mean depth of the southern lagoon increases from 10 m in the north to 20 m around Nouméa and up to 30 m further south. All recreational fishers can freely access the southwest area of the 4798 km² lagoon, except in the Yves Merlet marine protected area (MPA) in the southeast of the site. Ninety percent use the 43 public or private slipways to launch their boats. The remaining 10% are based in the marinas or moored in the different bays of Nouméa.

2.2. Data collection

In both study areas, data were collected through interviews with local fishers, using oriented questionnaires (Pollock et al., 1994), and maps charting their respective fishing grounds (Brent Hall et al., 2009; Close and Brent Hall, 2006). Detailed information concerning fishing practices were linked with each identified fishing area. Fishing powered boats are supposed to be associated with the highest yields, as often shown elsewhere in New Caledonia (Léopold et al., 2004). They give access to larger, distant and scarcely-exploited areas (Pradervand et al., 2003). The shoreline fishing was therefore not considered. As a result, our sampling and statistical unit was the fishing boat. In the northern area, 146 boat owners were interviewed (97 in rural villages and 49 in Melanesian tribes) and 532 were interviewed in the southern area (41, 180 and 311 in rural, peri-urban and urban areas respectively).

### Table 1

<table>
<thead>
<tr>
<th>Geomorphologic entities</th>
<th>Southern site (km²)</th>
<th>% compared with southern site (%)</th>
<th>Northern site (km²)</th>
<th>% compared with northern site (%)</th>
</tr>
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<tbody>
<tr>
<td>Barrier reef</td>
<td>254</td>
<td>5</td>
<td>114</td>
<td>15</td>
</tr>
<tr>
<td>Coastal fringing reef</td>
<td>105</td>
<td>2</td>
<td>122</td>
<td>16</td>
</tr>
<tr>
<td>Mid-lagoon reef</td>
<td>402</td>
<td>8</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td>Islet</td>
<td>3</td>
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</tr>
<tr>
<td>Soft lagoon bed</td>
<td>4034</td>
<td>84</td>
<td>483</td>
<td>64</td>
</tr>
<tr>
<td>Total lagoon area</td>
<td>4798</td>
<td>100</td>
<td>756</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 2. Overview of the social and natural environments in both study areas. The VKP study area is located on the top right of the map and the SW lagoon study site on the bottom left. The number of inhabitants for each locality is taken from the 2004 population census (ISEE/OE, 2007). Main reef structures and mangroves are represented as well as the locations of public wharfs.

All information were gathered about boat characteristics (length, engine type, registration year) and fishing activities (average catch per fishing trip, average catch per target species, average number of fishing trips per year, destination of the catch). The identification of fishing areas was facilitated by using Landsat7 pictures at 1/130,000th scale and marine maps at 1/770,000th scale in northern and southern sites respectively. The sampling strategy lightly differed between the study sites. In the southern case study, the sampling was stratified by type of day (weekdays and weekends), as well as the use rate of public wharfs. Samples depended on day types and their sizes were proportional to the attendance of recreational fishers. The research period covered an entire year (November 2004–2005). Additional questions were asked about the fishers’ motivations for fishing. In the northern area, the sampling took place during a three-month period between September and November 2007, and was spatially stratified. Boat owners from Melanesian tribes were almost exhaustively sampled at their home (due to their overall low number) whereas boat owners from villages were sampled randomly at each public wharf.

2.3. Statistical and spatial analysis

In Melanesian tribes, all boats were recorded during data collection. Such a visual process could not be conducted in other localities. In both study areas, the number of active boats in non-tribal localities had to be estimated. In the VKP and the SW lagoons, 645 and 12,738 boats have been recorded in the archives of the New Caledonian Marine Registration Office since 1940 respectively. Boat destruction over time and the fact that some boats are not used for fishing meant the size of the present fleet was assumed to be much lower than these records and was estimated by cross-checking historical and interview data.

Despite the two-year span between studies, we have assumed that data were comparable because the number of new registrations in the northern area was low during this period. Five four-year periods were defined (between 1988 and 2007 for the northern site and between 1986 and 2005 for the southern site), and a sixth period grouped all previously registered boats. The number of active boats per locality was then calculated by recurrence for different boat length classes (3.0–4.0 m, 4.1–5.0 m and >5 m in the northern site; 3.0–4.0 m, 4.1–5.0 m, 5.1–6.0 m and >6 m in the southern site). Two hypotheses were considered: 1) 100% of the boats registered in the most recent period (2004–2007 or 2002–2005 depending on the study site) were still active at the end of those periods; 2) the fishing activity of an active boat did not depend on its registration period. The sampled ratio of boats was therefore linked only with their activity and not their age.

The formulae for the northern site are:

\[
R_{l,t} = \left( \frac{N_{l,t}}{N_{l,0}} \right) \times \left( \frac{N_{l,0,2004-2007}}{N_{l,0,04-2007}} \right)
\]

where \(N_{l,t} \): number of matriculated boats of length-class \(l\), registered during period \(t\), in locality \(l\), \(N_{l,0} \): number of registered boats of length-class \(l\), registered during period \(t\), for all localities, \(N_{l,0,2004-2007} \): number of sampled boats of length-class \(l\), registered during period \(t\), \(N_{l,0,04-2007} \): number of active boats of length-class \(l\), in locality \(l\), \(R_{l,t} \): activity rate for boats of length-class \(l\), registered during period \(t\). It is assumed to be equal in all the localities considered, and hypothesis 1 gave

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The same formulae have been used for the SW lagoon with appropriate periods and length-classes. Hypothesis 1 and 2 were validated using the sample data.

For both study sites, statistical inference was used to estimate annual fish catch, effort and yields, and related confidence intervals, through a posteriori two-way stratification (Bryant et al., 1960). The two strata considered were “boat length-class” and “locality” (northern area) or “group of localities” (southern area). Data were then aggregated across localities to present results according to the different ways of life categories previously defined (urban, peri-urban, rural and tribal).

Where \(C_{l,t} \): total annual catch of length-class \(l\) in locality/group of locality \(L_{l,t} \); mean annual catch per boat of length-class \(l\) in locality/group of localities, \(E_{l,t} \): annual effort (number of fishing trips per year) of length-class \(l\) boats in locality/group of localities \(L_{l,t} \); \(Y_{l,t} \): annual yield (catch per fishing trip) of length-class \(l\) boats in locality/group of localities \(L_{l,t} \).

Each zone visited during a fishing trip was digitized and integrated into a GIS (ArcGIS® software). The catch observed in a given zone was then cross-referenced with the total production of each of the sample strata. This made it possible to redistribute the total extrapolated catch per stratum between the different individual fishing zones. This procedure assumed that the sample zones were spatially representative of the fishing grounds exploited by the whole fishing fleet of the stratum. The same procedure was applied to fishing efforts.

A spatial mesh was superimposed over the fishing zones to homogenize fishing maps. For each hexagonal pixel of the mesh, the sum of the catch and effort values of all zones included in the pixel was attributed to the pixel. This sum was calculated proportionally to the area comprised by the pixel to avoid overestimations. The hexagonal pixel shape was shown to provide an improvement in spatial indexes over an equivalent square shape (Tirunelveli et al., 2002). The pixel surface was 21.6 ha and 86.4 ha in the northern and southern sites respectively. This level of accuracy took into account the spatial extent of both lagoon areas and the accuracy of the maps designed to record individual fishing grounds. Based on these grids, the catch values (kg/pixel) were converted into catch values per surface unit (kg/ha) to facilitate the comparison of the production levels between both research sites.

3. Results

These surveys provided the first quantitative estimations of informal fishing activity in both study areas. Reef and lagoon catches were estimated at 170 t/year (225 kg/km²) and 1141 t/year (238 kg/km²) in the northern and in southern lagoons respectively, far higher than the annual catch of all professional fishers which reached about 500 tons in New Caledonia in 2006 (David et al., 2010). Catch composition differed between areas. It consisted mainly of Lethrinidae, Acanthuridae and Mugilidae in the VKP lagoon area, whereas Serranidae, Acanthuridae and Lutjanidae dominated the landings in the SW site (Fig. 3).

The active fishing fleets in the southern and northern areas were estimated at 3942 boats (31% of the total boat population registered within the zone) and 312 boats (36% of the total registered boat population) respectively. Eighty-eight percent and 100% of interviewed boat owners were involved in fishing at least once a year in the SW and VKP lagoons respectively. Although the technical characteristics (boat size and engine specification) of the fleet in the southern area were greater than those in the northern area, fishing data showed that production values per boat were higher in the north than in the south where, given the high demographic pressure, the mean marine area per boat was smaller (Table 2).

Fishing activity varied in accordance with ways of life in both study sites (Fig. 4). In the northern area, it was more intense and...
productive in Melanesian tribes than in villages though boats were generally smaller and fishing grounds closer to the shoreline. Similar results were shown in the southern site where urban fishers, who composed the largest group of fishers, usually owned larger and more powerful boats. Paradoxically, they travelled shorter distances on average and displayed the weakest effort and yield levels per boat. Rural fishers from both sites displayed similarities in terms of the mean boat size, engine power, catch-per-unit effort (CPUE) and distances to fishing grounds. However, trips were 11 times more important in the southern than in the northern area, and annual yields per boat were 2.4 times higher in the northern area than in the southern one (Fig. 4).

The fishing areas included 237,000 ha of soft seabed (34,500 and 202,500 ha in the northern and southern sites respectively) and 245,000 ha of coral reef (38,000 and 207,000 ha in the northern and southern sites respectively). Depending on the habitats, the fishing pressure varied significantly between the two sites and within each site (Fig. 5). In the northern site, it reached 4.3 trips/ha as opposed to 17.6 trips/ha in the southern area (respectively 0.1 and 0.2 trips/ha on average). In the northern area, the exclusive fishing area of the Oundjo tribe appeared to be the most intensively fished site. Most catches originated from the barrier reef and the back reef, except in the extreme north and in the mangrove edges, mainly at the river mouths. In the southern site, fishing pressure was higher in coral habitats (mid-lagoon and nearby islets reefs), on the shores of towns and villages, by the reef passes and in Prony Bay. The waters surrounding Nouméa were particularly frequented. This was also the case in areas situated less than 15 km from any launch ramp and on the barrier reef in the extreme south.

On the whole, fishing effort spatially correlated with the production levels (Pearson correlation coefficient = 0.438, \( n = 6691 \) observation units, \( p < 0.001 \)). The catch was proportional to the frequentation and therefore generally followed the same patterns as the fishing effort (Fig. 6). In particular, the surfaces of the pixel...
Fig. 5. Annual fishing effort (number of fishing trips) per ha in both study areas. Discretization inspired by Jenks method (natural breaks).

Fig. 6. Annual catch (kg) per ha in both study areas. Discretization inspired by Jenks method (natural breaks).
surface where production reached 10 kg/ha were 11 times greater in the south than in the north (24,192 and 2203 ha respectively, or 8.4% and 3% of respective pixels where fishing occurred). However, surface yields spatially varied from 0 to 317 kg/ha and to 53 kg/ha in the SW and VKP lagoons respectively depending on boat frequentation and marine habitats. They reached the lowest values on soft seabed areas (less than 2 kg/ha) that encompass very large areas (Table 1).

Results also showed that fishing habits differed depending on the way of life of fishers:

1. Fishers from Melanesian tribes showed significant activity in the northern site (57% of the estimated annual catch). Fishing grounds covered 47,000 ha and were mainly located on the mangrove borders, close to the coast, and at a 10 km distance from tribes (Fig. 7). Catches were dominated by Lethrinidae (25%), Mugilidae (18%), and Acanthuridae (14%). The soft seabed areas were less exploited (<1.7 kg/ha). The mean fishing pressure by this fisher category was 2.1 kg/ha in the whole area but was mainly located within the Oundjo exclusive fishing area (3.8 kg/ha). The activity displayed by the other tribes was less intensive.

2. Catches by rural fishers represented 44% and 6% of the total fish production of each study area respectively (1.1 and 2.4 kg/ha on average) in the north (66,000 ha) and in the south (27,200 ha) for a total of 260 and 92 boats respectively (Fig. 8). Their fishing practices showed that they generally visited the same types of habitats (mangroves, mid-reefs, soft seabed), preferably close to their areas of residence and closer than 15 km from their boat launch ramps. Acanthuridae were the major target in the north (26% of the catch) and in the south (33%). Lethrinidae and Serranidae showed opposite patterns (26% and 9% versus 6% and 18% of the catch in the northern and the southern sites respectively). Mugilidae were rarely fished. Rural fishers exploited the entire VKP lagoon area (apart from the Oundjo customary area) but showed selective fishing grounds in the SW lagoon. The barrier reef and bay beds were not widely frequented despite their proximity, unlike St. Vincent Bay where the activity was concentrated.

3. The highly mobile and numerous peri-urban fishers (1239 fishing boats, i.e. one boat for every 38 inhabitants) visited almost all the available fishing sites of the SW lagoon area, including the outer slope of the barrier reef up to the extreme southern reefs (191,000 ha in total). Catches amounted to 41% of the total catches in the southern site (Fig. 4) with a mean of 2.5 kg/ha (Fig. 9). They were mainly composed of Serranidae (24%), Lutjanidae (16%) and Lethrinidae (15%). However, the distribution was not even. The soft seabed areas far from the inhabited centers were unpopular, in particular in the very southern sector. The areas with high pressure were located close to islets and mid-reefs, within a radius of 15 km of Nouméa, and in St. Vincent Bay. The distances between launching spots and fishing grounds reached up to 80 km, mainly towards the south of the study area.
Urban fishers (2611 boats, i.e. one for every 35 inhabitants in Nouméa) were the most important group and caught 53% of the total southern production. As in peri-urban localities, Nouméa fishers scoured the entire SW lagoon (over 158,800 ha) from the various access spots. They also targeted similar fish species. The mean production (3.8 kg/ha)
concealed an important spatial variability (Fig. 10). Some highly localized areas – those located in an action range of 10–20 km around Nouméa – were heavily exploited in coral reefs (mid-reefs and islets reefs) and passes. The other reef was also targeted, as was the outer slope of the barrier reef in the south of the main MPA, in the south horn and in St. Vincent Bay. However, most of the coastline, the mangroves and the soft seabeds of the lagoon area were unpopular.

4. Discussion

The methodology used in this paper enabled us to conduct statistical and geographical analyses in order to determine the complexity of two fishery systems, while respecting the constraints of time, costs and the fishers’ access to information. Launch ramps constituted the best places to meet and obtain information about the recreational fishers with the minimum inconvenience (time spent per questionnaire). The accuracy of the zoning undertaken by the fishers undoubtedly depended on the scale used (Campbell, 1993; Close and Brent Hall, 2006). Given that the southern site was six times larger, it was not possible to use the same operating scale in both study sites. However, it was assumed that the spatial analysis conducted in the southwest lagoon enabled the collection of reliable data and the detection of potentially dubious areas where more refined studies could be carried out.

4.1. Definition and analysis of fishery geosystems

Quantifying and mapping the activities at the study sites allowed us to establish the spatial habits of the fishers’ ways of life. Ways of life were embedded within a socio-system that combined factors relating society and individual choices (Hilborn and Walters, 1992; Corlay et al., 1995; Béné and Tewfik, 2001). The fishers developed practices, drew up itineraries and territories according to spatial choices and strategies that were based on their representations and in line with a legal and statutory framework. By representation, we understand the fisher’s expectations, how he considers the resource and the fish (a piece of food or an opponent rather than an element of the ecosystem) and the benefits he derives from his fishing (food, conviviality, recreation etc.).

Our objective was to establish which factors affected the spatial distribution of informal fisheries and to deduce typical behaviors from these factors. We associated ecosystems to socio-systems that not only depended on the biological and physical environment, but also on management schemes such as laws and regulations. This approach corresponded to the concept of fishery geosystems developed by Corlay et al. (1995). It is defined as a social-ecological system, a composite and complex space, and the site of interactions between physical, biological and anthropogenic components (Rey et al., 1997; Berkes and Folke, 2002; Caill-Milly et al., 2003). The relative contribution of ecological and anthropogenic factors may vary according to locations and periods. Hence, time (at different stages) became a component that had to be integrated during the explanatory phase.

While adapting this concept to both case studies, some ecological and institutional similarities emerged. From an ecological point of view, species diversity on coral reefs was similar in these two areas (Chabanet et al., 1997), and so was the mangrove surface. From an institutional point of view, New Caledonian authorities in charge of fisheries within the coastal area used conventional regulatory measures for zoning and regulating the fishing pressure (fish quotas per boat, minimum sizes, protected species, fishing gears etc.), including the implementation of Marine Protected Areas (David et al., 2010). Despite the fact that the MPA network was more developed in the south, the management regimes could still be compared at both study sites.

The main differences were thus geographical (distance from the barrier reef and the resulting lagoon area, presence/absence of
coralline islets and lagoon bathymetry) (Andrefouet et al., 2007) and human. Both components interacted and generated four fishery geosystems based on respective ways of life categories:

(1) The Melanesian fishers’ means of production in the investigated tribes required a low level of financial investment. Moreover, the production levels per trip and the proximity of the fishing grounds were typical of subsistence activities and economic strategies. Production costs, catch levels and fishing durations were determining factors for the fishing activity, be it for the fishers’ own consumption or for informal sales (Lunn and Dearden, 2006; Schumann and Macinko, 2007) offering only a low level of household income (Hauck et al., 2002; Kuster et al., 2006). The geosystem characterizing the fishing activity in the Melanesian environment also reflected a historical-cultural logic. The spatial distribution of the activities displayed the existence of effective “fishing territories” that were forcefully claimed as exclusive (as in the Oundjo tribe) or non-exclusive. Our results suggested that the five Melanesian tribes in the area behaved differently through this double logic based on (1) their customary traditions (oriented towards the land or sea), (2) their geographical location on the seashore or inland, (3) their reliance on maritime resources and (4) their integration within the socio-economic network. As already observed in other Pacific regions (Bataille-Benguigui, 1989; Turner et al., 2007) and in New Caledonia (Bour and Hoffschir, 1985; Legaard, 2004), the economic development of the area is likely to alter this organization and practices (Craig et al., 2008).

(2) The case of the rural village fishers illustrated the consequences of the evolution of the New Caledonian economy since the 1960s. Unlike investment costs (boats, engine specification) and production costs (distances travelled), their activities were characterized by a lower intensity than in the case of the Melanesian tribes (annual effort and mean yield per boat). The sampling results showed that they mainly fished during weekends and on public holidays. These patterns reflected recreational activities. More precisely, they were traditional, if not cultural, in nature and could be explained by the country’s settlement history. Even if the situation is progressively changing, most village inhabitants were still descendants of settlers, deported people or economic migrants from the agricultural and mining sectors who immigrated as early as the end of the 19th century (Roux, 1984; De Decker and Devambez-Armand, 1992; Guiart, 1998; Anglevial, 2006). Kôné, Pouembout, and Bouloparis are examples of villages that emerged from the colonial, mining and penitentiary history of New Caledonia (Trépied, 2007). Recreational fishery has been anchored in the country’s pattern for a half-century (Loubens, 1978). The low cost of fishing equipment and abundance of resources, together with the general improvement in living standards over the past 50 years, explains why fishing has progressively turned recreational (Jollit-Boniface, 2007; Craig et al., 2008). Today, it characterizes the ways and customs of this population with one boat per 37 inhabitants. Moreover, the informal trade of catches tolerated until 1981 outside Nouméa (Assemblée Territoriale de la NC, 1968) could still influence the observed annual catch volumes. The close proximity of fishing grounds to places of residence could be explained by the concept of “friction of distance”, which means that “resources further away are less liable to be exploited than those close to port” (Lloyd and Dicken, 1977; Isard and Liossatos, 1979; Caddy and Carocci, 1999; Hunt et al., 2007). The location of fishing grounds far away from boat ramps depends therefore on the quantity and quality of resources that suit the fishers’ representations (Hutt and Jackson, 2008; Stuart-Smith et al., 2008). Moreover, the seabeds of some bays were poorly visited in the southern area because of the severe sedimentation coming from the runoffs of watersheds (Dumas et al., 2010). However, the comparison between rural fishers of both study sites should be qualified. The frequency of their activity and their annual catch in the northern area suggested a great heterogeneity of behaviors among the rural fishers around Kôné.

(3) The peri-urban fishers we encountered in the southern area displayed some similarities with rural fishers. They also fished recreationally although in a more scattered manner throughout the lagoon, and more occasionally. Peri-urban fishers only accomplished two trips per month on average (against three trips per month for rural fishers). They travelled the longest distances using larger and faster boats. Their favourite grounds covered a 10 km radius from the launch ramps. The budget allocated to this type of activity was likely to be much higher than for the two previous categories of fishers, which was consistent with the available socio-economic statistics (ISEE/OE, 2001). This broad spatial distribution probably depended on the purpose of the fishery itself which may be related to the geographical origins of this population. Most of the inhabitants of the peri-urban localities belonged to the rural exodus the country has been suffering since the 1960s, as a result of the economic development of Nouméa (Arréghini and Waniez, 1993; David et al., 1999; Bladinières, 2001). Expensive property rates in Nouméa along with good living conditions in the surrounding localities have prompted families to settle in the satellite suburbs (Doumenge, 1994; Derruelle and Sodter, 1999; Dussy, 1999). Therefore, in these localities, the fishers’ representations partly came from their rural origin and can explain the importance granted to catch volume. Thus, they tended to avoid the areas around Nouméa where fishing pressure was high, and preferred to fish where resources were more abundant or focused on emblematic species (large pelagic and reef fish).

(4) The urban area of New Caledonia, comprising 2611 active boats, generated strong frequentation of the lagoon surrounding Nouméa, with the remarkable exception of the mangroves. In particular, the creation of the large Aboré marine reserve (no-take MPA) on the barrier reef off Nouméa in 1994 pushed the fishers further north and south. The fishers’ activities in this area were similar to the previous case in terms of areas visited, trip frequency and allocated budget, except for yields that remained 1.6 times lower (and the lowest of the two sites studied). This result implied that trips were not exclusively oriented towards fishing (perhaps focused on visits to the islets and the MPA, snorkelling or sea-touring, for example) and/or the low importance of the quantities fished.

4.2. Contribution of the fishery geosystems to management

The spatial and social analysis of the informal fishing activity demonstrated that the fishers’ way of life was a major structuring factor. This spatial distribution primarily depended on the ecosystem “supply”. However, this was not the only driver. In our two case studies, the activities of each category of fishers were carried...
out in targeted areas, and the maritime (physical and biological) environment did not solely determine the observed variations. In fact, economic and social parameters interfered through a “possibilist approach” (Vidal de la Blache, 1902): “nature proposes, man disposes” according to the purpose (food production, recreational, commercial etc.) and his representations of his own fishing activity. In the case of recreational fishery, for example, the logic mainly depended on the fishers’ representations or on the fact that fishing had an amenity-based role that could lead fishers to seek out less-visited areas (Chambers and Price, 1986; Navarrete et al., 2004; Smyth et al., 2007).

The analysis of the southern case study showed that the fishery geosystems of the southwest lagoon was established in accordance with the socio-economic evolution of New Caledonia since the early 19th century. The nickel boom of the 1960s in and around Nouméa, the Melanesian villages and among tribes located close to mining sites represented a crucial step in this process. The employment perspectives for low qualified workers and the high incomes in the nickel industry between 1960 and 1973 turned Melanesian tribal fishers away from the commercial fishing of Trochus and sea-cucumbers that provided them with a subsistence income (Bour and Hoffschir, 1985; Conand, 1987; Legeard, 2004). Peri-urban and urban geosystems in Nouméa and the peripheral localities took shape over a 50 years course.

These evolvinginformal fisheries in New Caledonia, in particular in the southern region, can provide a historical model for the future of the fishery geosystems in response to economic drivers, in a given social context and maritime environment. It can provide a yardstick for possible future development in the northern area, where there is a resurgence of mining after the construction of a metal-processing plant. The current economic development in the Koné region is unprecedented in the country. The rapid economic and demographic growth suggests there might even be an acceleration of the process described in the southern Province. In any case, it is highly likely that it will alter the present structure of informal fishing activities as it did in the south (Guillemot et al., 2009).

However, while the nature of these external constraints appears similar, the geographical and social components are different in the northern site. Indeed, the lagoon area is six times smaller than in the southern region, shallower and mangroves cover 25% of the area. It is six times less populated than the southern localities in the 1960s and the composition of the population is more heterogeneous. The larger influence of Melanesian communities on the coastal area also plays an important role on the structure of informal fishing activities and importance of catches, whereas it was negligible in the southern area. Moreover, it played a structuring role in the spatial determinism of fishing practices. The migration of newcomers from other New Caledonian regions may lead to increase conflicts from overusing fishing grounds and misreading local practices (Yandle, 2007; Guillemot et al., 2009). This will be emphasized by the fact that the whole northern study area is already being exploited, whereas in the larger southern site some areas remain free of frequentation. Thus, the Melanesian geosystem causes uncertainty over the evolution of the informal fisheries in the Koné region that cannot be considered from the recent history of the southern case (Horowitz, 2008). This model is therefore more suitable for interpreting possible changes to the rural geosystem because, in many respects, it looks like its equivalent in the southern area. Together with urbanization and the expected socio-economic change, it can follow the same type of transition towards peri-urban and urban structures as suggested by the behaviors already observed among some fishers in Koné.

Therefore, the complexity of the current distribution of fishing activity in the two study areas appeared to be inherited from an ongoing adjustment of the different fisher groups, in response to a century of changes experienced by New Caledonia. These adjustments included a spatial redistribution of the activities, an evolution in the fishers’ representations together with the purposes of fishing itself (Radomski et al., 2001; Turner et al., 2007). If not adequately anticipated, they can be weakened by a radical mutation in the economic and social context, such as the expected evolution in the Koné region for the next decade (Poignonec, 2006). Solutions provided by the public authorities to manage the activities in the maritime area around Nouméa may thus be partly unsuitable in the case of Koné where the human context is to some extent different. The challenges involved in the preservation of resources specific to the Koné area derive from fishing pressure and a social structure that may get more complex in the short-term. It is therefore necessary to create new forms of local management to integrate the fishery systems and their spatial references (Adams, 1998; Salas and Gaertner, 2004).

5. Conclusion

This paper deals with the difficult issue of informal fisheries in complex territories where the monitoring of the exploitation has always been difficult to comprehend. In order to address this complexity and comprehend the activity of informal fisheries, we utilized and adapted the concept of fishery geosystems based on environmental, social and management issues. For that purpose, survey methods were developed in two sites to collect the most relevant and accurate quantitative and spatial data using appropriate sampling techniques, questionnaires and maps during fisher interviews. In both sites, we gathered the same types of data and adapted survey methods to local conditions. Robust statistical and spatial analyses using GIS allowed us to generate the first annual estimations and draw maps of informal fishing activities.

We found (and quantified) that subsistence and recreational fishers were likely to exert a higher fishing pressure than professional fishermen on coral reef resources in New Caledonia. A large part of the forms of exploitation and the spatial appropriation could have been explained by the fishery geosystems. We demonstrated that ways of life were appropriate to address the social issue. They allowed us to distinguish Melanesian, rural, peri-urban and urban geosystems that showed different fishing practices and geographical patterns. The spatial structure depended on the purpose of the activities and on the fishers’ representations as shaped by the New Caledonian culture, the natural environment and the history of the country that has been significantly marked by the economic context of the last century.

The comparative study of the fishery geosystems of the west coast of New Caledonia enabled us to understand how informal fishing activities have been linked to the dynamics of the nickel mining industry in the country. These interactions, still prevailing today, may re-emerge in the Koné region in the northern Province with the establishment of the country’s second metal-processing plant. Indeed, the case of the southern area provided information about the various types of informal fishery geosystems that may develop in areas facing similar social and economic constraints. Rapid adjustments of the tribal and rural geosystems would be essential in the VKP area to cope with the brutal economic and demographical changes affecting fishers’ behaviors in the short-term. The vulnerability of the social and natural systems to the economic constraints already experienced in New Caledonia, calls for the promotion of approaches linking informal fishing activities to their spatial organization.

In order to improve the approach developed in the present study, it would be valuable to consider beyond the evolution of the social diversity, the temporal parameters affecting the fishing activities (e.g. related to seasons and weather conditions) and the spatial variability of the different fishing gears implemented.

This paper showed that the study of fishery geosystems represents an innovating approach that can help to determine prospective fishery management actions. Our results could, in this regard, be integrated into management scenarios, with the aim to assess, spatialize and predict evolutions of the uses of the lagoon and the marine resources, to determine potential conflict areas, overfishing situations, etc. Local authorities facing coastal management issues could then anticipate and adapt their management strategies in consequence.

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