Partie 4

Words, practices and representations around the reefs

Coordinator: Catherine Sabinot

For three millennia, people have been connected to reefs. They spotted them from their outrigger canoes, discovered passes that allowed them to reach the land and settle close to the reef flats and slopes that provided a variety of fish resources. For Kanak people, the lagoon is an invisible world inhabited by ancestors and crossed by the "paths of the dead". It is a place characterized by stories, memories, and fishing trips ("coups de pêche"). Researchers in the social and human sciences, together with their colleagues in natural sciences, decipher what the reef means to New Caledonians.

Chapter 28

Three Millennia windward of coral reefs

Christophe Sand

The Isle of Pines on the horizon. © P.-A. Pantz

Sea-foam on the horizon of a new land

In the insular system of New Caledonia, waves breaking on a reef are always in sight of coastal clans. About 3,000 years ago the first Austronesian-speaking explorers approached the enigmatic and seemingly endless land mass of the northeast coast of Grande Terre, which they could see on the horizon. As they approached the surf of the waves breaking on coral they searched for passes through the reef.

At this unique and fleeting moment in history, the first discovery of a new land, sailors were not interested in the potential resources of the marine environment, but rather in the promise of freshwater, there, on land, ahead of the pass which they entered with their outrigger canoes.

These oceanic explorers originated from the "Great Coral Triangle" region to the far northwest, between the islands of Southeast Asia and northern Melanesia. Knowledge of the reefs had been part of their cultural background and ancestral memory from the beginnings of mankind. When exploring the New Caledonian Grande Terre, they quickly understood that they were faced with one of the most extensive coral reefs they had ever seen. These reefs were much larger than anything they had discovered since leaving the Solomon Islands, colonized tens of thousands of years ago, to venture to islands and archipelagos that no man had ever explored before.

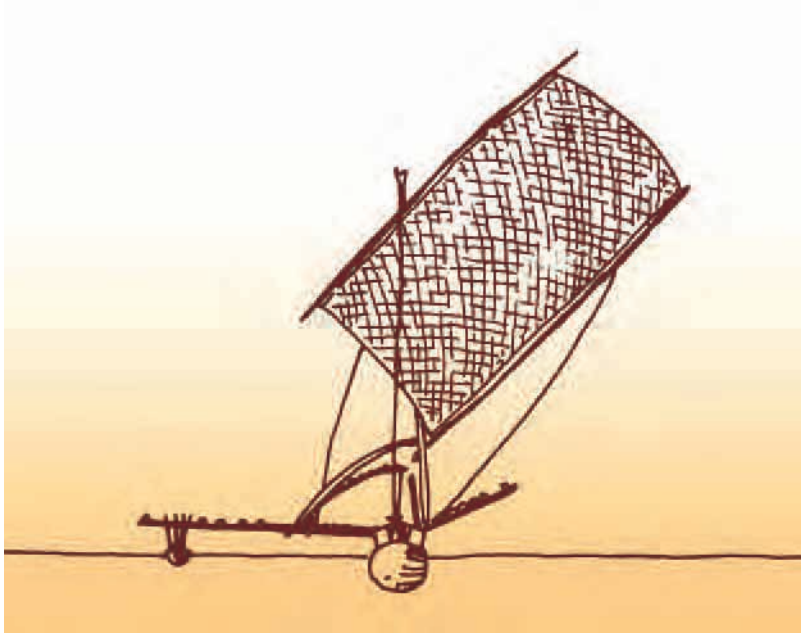


Figure 1: Possible shape of a canoe used for the first settlement in the New Caledonian archipelago 3,000 years ago. © C. Sand

View of the dune of the first settlement of Patho on the east coast of Maré in the Loyalty Islands. © C. Sand

When the reefs were truly "untouched" by any anthropogenic impact

These early groups of sailors had one main objective when they set sail on their canoes for the unknown, beyond the horizon (Fig. 1). They wanted to discover new land and establish permanent settlements. Those who reached the New Caledonian archipelago, quickly realized that the winds had blown them to colder latitudes than those from which they had originated, and that the geology of Grande Terre was very different from anything they had seen during their journey. The terrestrial environment most familiar to them was the coastline, and they demonstrated a clear preference for establishing their first settlements here: a beach near a freshwater spring, close to a coastal reef flat for food, and the whole settlement placed so as to enable quick access to the open ocean through a channel in the reef. The sites of Naïa, Nessadiou, Koné or Koumac on the west coast, Goro or Pouebo on the east coast, and Keny or Patho in the Loyalty Islands all feature these characteristics.

In these early settlement sites, archaeological excavations have uncovered mainly the remains of earth-related artifacts such as pots decorated with motifs of the Lapita tradition, and stone axes. However, the study of shellfish remains revealed a tradition based on the exploitation of all available marine environments. The presence of gastropods, such as trochus and cones, is an indication that at least part of the group's food gathering was from the reef environment. Similarly, the fish bones found in the refuse pits of the Lapita sites in the Loyalty Islands, indicate that Scaridae (parrotfish) were the predominant fish caught from the coral environment, probably using mainly fishing nets. Some carnivorous lagoon fish were caught using simple hooks made from seashells.

Today, it is difficult to imagine what the richness of these marine environments, in the New Caledonian archipelago would have been at the time of the first settlement 3,000 years ago. This was before the repeated harvesting of shellfish and the increase in fishing by expanding clans, which significantly depleted trophic densities. On the central west coast of Grande Terre, where the lagoon is narrow and

the barrier reef is rapidly accessed from the beach, archaeological studies have indicated that the economy of Deva's coastal groups had been heavily dependent on seafood for a very long time. For nearly two millennia, in order to avoid the overexploitation of the reef environment, families lived semi-nomadically and were organized in sparsely populated territories. They moved regularly from one area to another along the coast to avoid depleting resources.

Soil on coral

It would be a mistake to believe that this kind of direct harvesting by man was the sole reason for the gradual depletion of coral reefs over the centuries and millennia that followed the first settlements. A massive but indirect phenomenon has considerably contributed to the changing characteristics of the lagoons of the New Caledonian Grande Terre: land erosion. The people of Oceania are, before all, farmers, growers of yams and taros, but also of banana trees, sugar canes, and so on. To expand their crops, the descendants of the first Lapita farmers gradually burned the dry and wet forests that covered the vast majority of the island's terrestrial environments. In a tropical habitat, where natural fire is extremely rare and where thick layers of humus had developed over time, the disappearance of trees led to the repeated erosion of surface soils. Soils have been stripped down the slopes during intense rainfall events, such as tropical cyclones, and the alluvium have been carried away by creeks and rivers into estuaries. The estuaries have gradually silted up as a result, leading to the expansion of coastal plains, sometimes stretching over several kilometers, and the development of mangroves over former coral sand beaches (Fig. 2). Fine particles of sediment were washed into the sea and re-deposited on coral spores in a process that today would be called "pollution". The imbalance suffered by reef environments close to estuaries, has had a cascading impact on the entire food chain, from corallivorous fish to mollusk species.

Living in a fossil coral environment

The traditions of the Loyalty Islands groups to the east of the New Caledonian archipelago have been profoundly influenced by their singular natural environment of raised fossil coral reefs. One of the challenges in living on karst islands is the absence of watercourses, as the porosity of the ground does not allow the formation of creeks. Therefore, the coastal groups initially collected some of their water from the runoff of the freshwater lens (Ghyben-Herzberg lens) on the beaches at low tide. However, this became no longer possible when some families, attracted by more fertile agricultural soils, began to settle on the inland plateaus. The presence of coastal runoff meant that water was present inside the limestone rock and expeditions were organized in search of it in the coral plateaus' caves of the Loyalty Islands.

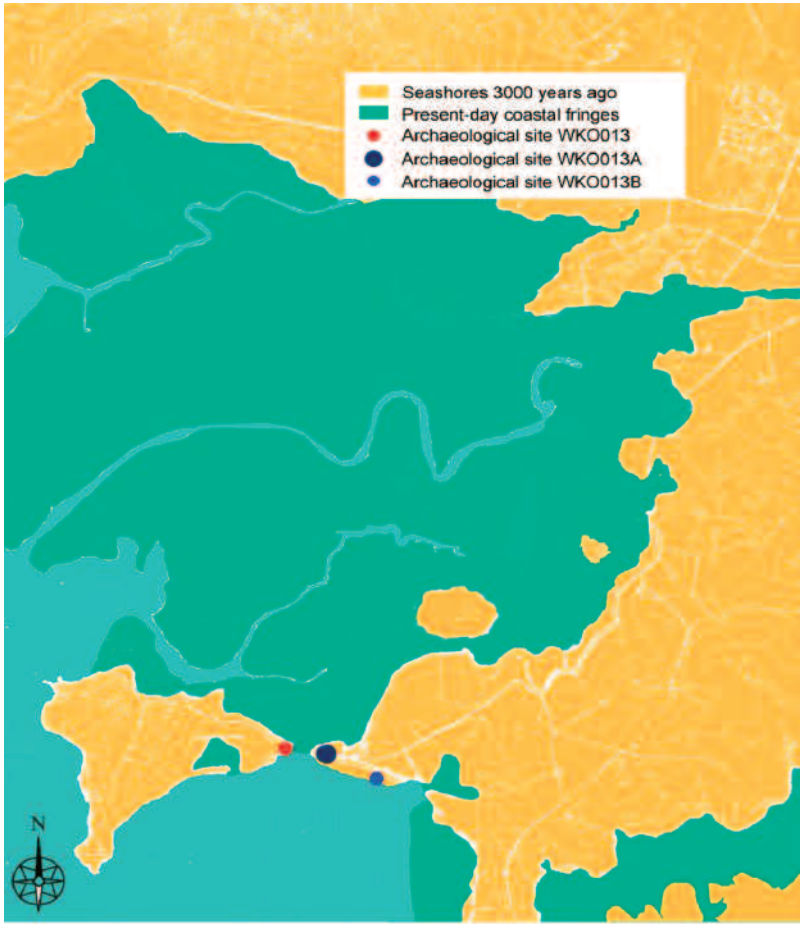


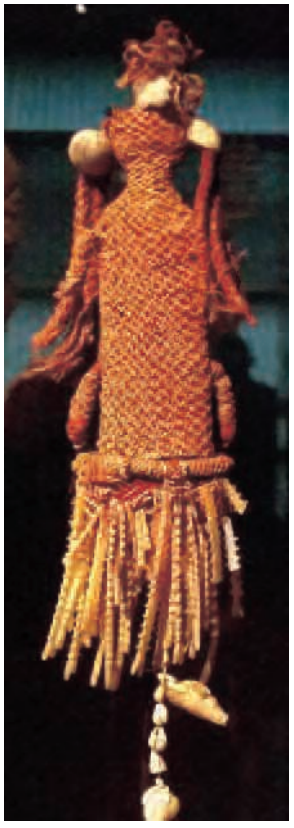
Figure 2: Extension of the estuary of the Koné River over the last 3,000 years. Each code corresponds to a different Lapita site of Foué beach, which is the eponym site of Lapita. © C. Sand

Artificial basin made of blocks of broken stalactites, built in a cave on the island of Tiga for the collection of infiltration water. © C. Sand

These difficult and dangerous explorations, lit only by torches made of dried leaves, led to the discovery of percolating zones where water dripped from the ceilings, and even formed natural pools sealed by the millennial deposits of calcite. Since then generation after generation of men ritually organized visits to the womb of Earth to collect freshwater. They marked their visit with artwork on the cave walls, using their hands as stencils; they used large giant-clams or nautilus shells to collect water drops falling from the ceiling; they set up underground paths to guide themselves in the darkness; and sometimes even created artificial basins to facilitate the accumulation of water.

Mother-of-pearl Kanak exchange currency

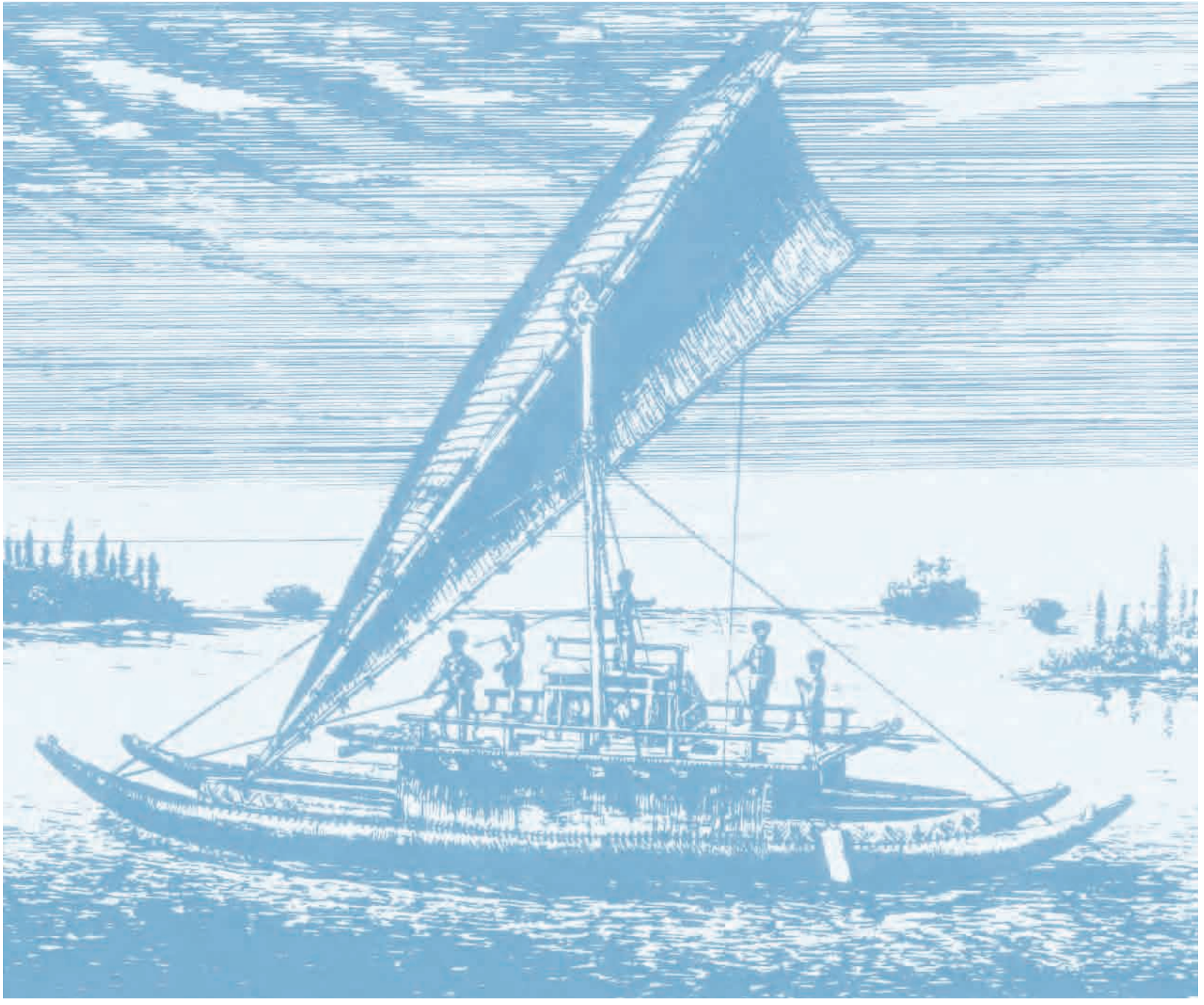
From the end of the first millennium A.D., the development of new cultural traditions throughout the New Caledonian archipelago led to the emergence of a "Traditional Kanak Cultural Complex", characterized by a massive intensification of the use of the natural environment. This has led to a sedentarization of the clans and a growing interest in protecting the island environment. This cultural evolution was also marked by the emergence of new objects for exchange between groups, in particular the conceptualization of a unique form of traditional Kanak exchange currency, characterized by the presence of tiny mother-of-pearl pendants. These are meticulously cut, with lateral projections perpendicular to the central axis, and have a millimeter-shaped hole for attaching a string made with vegetal fibers and braided flying fox (a species of bat) hairs. The mother-of-pearl shells that were used to make these objects that were only a few centimeters long, were collected from reef environments. The oral traditions in the center of Grande Terre say that Kanak money-makers from the region of Houaïlou, on the east coast, followed customary paths through the central mountain chain to collect this raw material in the Bourail region on the west coast, where the barrier reef is only 1.5 km from the coast.



Kanak exchange currency with mother-of-pearl pendants. © C. Sand

James Cook's crew approached the area of Balade, in the northeast of Grande Terre, in September 1774. On several occasions during their short stay, the English sailors were able to observe canoes going out fishing on the reef. This historical connection between the Kanak and the sea is evidenced by the presence of seashells in inland valleys and on plateaus, which are discovered during archaeological surveys throughout the archipelago. The mollusks were transported alive, together with the dried salt packages needed for food preparation, as part of the exchanges between coastal and inland groups.

Archaeological studies also reveal that marine life was illustrated in rock art, which depicted turtles or fish. These drawings and engravings on cave walls or beach-rock slabs are the legacy left by these "people of the sea" as they returned from fishing trips in their canoes out on the New Caledonian reefs. In its protective rock-shelter at the top of Faténaoué-Hwatenewe piton, the mummy of Chief Hmaè Kahouta, a "man of the land", also looks beyond the plain of Temala to the great passageway in the reef of Voh, a place where souls travel to reach the "land of the dead".



Large double canoe in a bay of the Isle of Pines. © Musée d'Océanie, la Neylière /drawings from nature, P. Bournigal

Painted representations of turtles on the wall of a cave at Bocage Cape (Houaïlou). © C. Sand

Box 22

Megalithic fossil coral fortifications

While the caves in the fossil coral have served as an unexpected source of freshwater for Loyalty Islanders, karst has also been used regularly as a building material. The most spectacular constructions are located on the central plateau of Maré Island, where, during the first millennium A.D., the inhabitants built megalithic fortifications. These were raised by extracting large monolithic fossil coral blocks from open-air quarries at the base of karst pitons. Some of these blocks could weigh several tons each and had to be pulled by hand to the construction site, sometimes several kilometers away from the quarry. There they were placed one above the other, up to 4 m in height, to form retaining walls of 10 m wide and several hundred meters long. These forts had monumental gates where some of the largest blocks were placed.

Monumental entrance to the megalithic fort of Hnakudotit, built on the Maré plateau using fossil coral blocks. © C. Sand

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Chapter 29

Reefs, speech and people

Emmanuel Tjibaou

The mouth of the Ouaième River. © P.-A. Pantz

In New Caledonia, as in many Pacific island societies, the connection to the marine environment and its associated reef lands is essential to understanding the political and social organization of human groups. Here, the sea and reefs are a direct extension of the land where the duties, practices and obligations of Kanak customs apply. The similarity between perceptions of land and of maritime space has many possible explanations. While island societies all develop a good knowledge of navigation and the ocean, the sea is also their origin myth.

"The Path of the Dead"

One of the keys to understanding this particular relationship between man, reef and sea comes from representations of what is commonly referred to as the "path of the dead" in northeastern New Caledonia. For example, in the region of Hienghène, in the valleys as well as along the coastline, it is usually recognized that when a person dies, his spirit disconnects from his body. The spirit then uses a path

Ilot Kaavo, marking the entrance of " The Path of the Death", Northern region of Belep. © E. Tjibaou

that will take him from the deceased's home inland (from the creek to the valleys, the stream to mountain ridges), to the entrance of the Ouaième[14] River. This "spirit trail" extends along the bottom of the river, past the guardian of the Hwaiwai Passage, to the spirit kingdom facing the Hienghène pass on the edge of the Tao Reef. In the Fwâi language of Hienghène, this is called *sêêdan ne vi danu*, literally meaning the "path of spirits". This cycle of completion, the drying out of the vital processes in Kanak people, constitutes an initiatory sequence that recalls one's own journey through life: the individual emerges from the flow of the original matrix where the spirits dance at the bottom of the oceans at Tiduuwon[15]; all his life he makes imprints in the ground, moving away from this ocean of origins, which his spirit finds again in death. In the northern region, representations associated with the reef and the underwater environment refer to both the legitimacy of death and the necessity of life.

In the kingdom of the dead, two mythical characters (Doibat and Hwaiwai) represent this original omnipotence of the reef and the underwater environment. Doibat, the spiritual power of the underwater world is depicted with plants and trees covering his body and is the guardian of the entrance to the kingdom of the dead on the Belep archipelago, north of Grande Terre. He is of unequalled grandeur and sits in Lolon (Belep), harassing the spirits of the dead that appear in front of him, before sending them through an underwater passage behind Pott Island, north of the Belep Islands. Hwaiwai, who takes the form of a shark or dugong is the guardian of the entrance to the kingdom of the dead in the Ouaième River in Hienghène and waits underwater with a torch for the spirit of the deceased. He gauges his ear lobes with a stake to verify that his ears have been pierced, a sign of his initiation by the living. These two mythical characters stand at the entrance to the underwater world to ensure that these environments are not defiled by the living. Both organize the passage of the deceased spirits from the world of the living to that of the supernatural underwater spirits in accordance with an established test that reinforces the proper functioning of the kingdom of the dead and which allows them to identify any intruders.

[14] Ouaième: the Weyem River located on the northeast coast bordering the municipality of Hienghène. This river is relatively well known in the region for its symbolic place in oral traditions, especially as a gateway to the kingdom of the dead. This is the last watercourse in New Caledonia where a motor boat is required to cross it.
[15] Tiduuwon: toponym in the Fwâi language of Hienghène, referring to a locality at the mouth of the Ouaième River, near the pass.

Marine species and meaningful places

Certain species of the marine fauna are associated with this spirit underwater journey. These include sharks and particularly basking sharks, sperm whales and other whales. The appearance of these creatures at the surface is seen as a manifestation of the spirits of the kingdom of the dead. Additionally, these animals, which are emblematic of marine spiritual forces, are found in many origin myths in northern New Caledonia. The place of these mythical species at the heart of the marine and reef systems, testifies to the knowledge that Kanak people have of their environment, and also to their imaginary power. Here, reefs, sand banks, coral cays, reef slopes, and passes are mythical or historical markers of human knowledge throughout the course of life. The relationship between man, reef and sea is perceived as a particular entity where the individual finds himself, and where he needs to navigate within an original and densely populated community and follow specific codes. These rules of coexistence between marine and human species are learned from a very early age through games and story-telling associated with rituals, which are carried out for the respect of underwater life. While knowledge of the paths of customary alliances is necessary for someone from inland in order for them to become an accomplished man, for the people of the coast mastering marine currents, passes and trade winds is paramount for crossing this threshold into manhood.

Box 23

Mourning speech to maternal clans

This speech was spoken in Paicî language by Umätu Michel Tiapi Gönô, the Chief of Ometteux (Poindimié, northeastern New Caledonia) and recorded by Dominique Paabu Oye in July 2005 at the Bayes tribe in Poindimié. In essence, the speaker said: "We invited you and called you down this path, to come in through this lane and be present here because your nephew's foot bone (the tibia) has burst and cracked, and the vitality in him was also broken, and he is no longer in the midst of this assembly. He no longer has what makes him live and talk and walk, he has turned his back on the sun and moon. It was taken up by the devil's vortex, up there in the middle of the air, and carried away by the current, down there in the expanse of water with no horizon, and then he was stranded [as a shipwreck] onto the reef flat [fringing coral reef or coral massif contiguous to the land] at Wénégéi[16]. And he entered the dance at Pijèpaa[17] [the dance of the dead]. You are going to take him up there on the stone from which he comes, on the stone object of his respect and his taboos. You will entrust him to the grave and the land of darkness. This is the tree, the fir tree that symbolizes your nephew's disappearance. You will take it and bring it to X [the names of the clan and sub-clans of the maternal uncle who cannot be revealed outside a restricted circle of people]. This is the end. It is over."

« Pwi a popai â nä-é i nä pââ : "bë to mä paci pââ nä-guwë itë-mê nä-näigé bèè-nî nä guwë tö-mê nââ görö-igé bèèni nä guwë tö-mê nau coo-nî nä taö mä mä-biti i duru-â pwi nîaa go-wë nä ta-biti i jawé wâdo-é nä tiëu-é géé nââ pa-ba nä utê go-rë nî ba é-jè ningä mä cèkëé mä cö-mä-cö é nä-cëù tärä tötù mä parui â-jè cëù-é i u-kärä-duée dö gopaé-ré-näo â-jè dëti-é i duru-jawé wâ-boo nä-jawé tacî â-jè tagötù-é nä-gö i paara kë wânâgëi â é-jè pärä nä i cäbu-kë-Pijèpaa guwë mwâ popaé dö-nö-gö i atù nyââ kêê nä-ia-é té-géé-goo i atù au-pi-too mä au-paa-pwicî kêê guwë töpwö-é nââ näcè oolaa mä cè pwaduu wëé-nî i upwârâ cämù kärä nä-tiëu pwi nîaa go-wë guwë mwâ pa-dö nââ… wëé-nî â näbwé" ».

Extract from the 2006 Paicî-Cèmùhî Report. Surveys of the Heritage and Research Department, ADCK-CCT, Paicî-Cèmùhî Customary Council (2006).

[16] Wénéguei: toponym, clan name and chiefdom of the south of the Ouvéa atoll, one of the three Loyalty Islands (New Caledonia).
[17] Pijèpaa: toponym and clan name of the northern part of New Caledonia. This patronym is generally associated with the status of those who perform funeral rituals within a chiefdom.

View of the Fayawa pass from Mouli, Ouvéa. © P.-A. Pantz

In the *jahma*[18] sacred narratives of the Hienghène-Pouebo region and the north coast, the ocean is described as a continuum of the land and it is said to be governed by customary authorities who are responsible for the management and maintenance of these underwater areas. The oral traditions related to these topics demonstrate the specific political organization of underwater spaces, which visitors must respect (for example, the customary practice of *huremeno*[19] before fishing in certain areas; or *hiri ne buai*[20] when passing through certain places, etc.).

It should also be remembered that these spaces, even without any indication of human presence, may be governed by specific rules:

- a "customary sea" depending on a chiefdom on land (Hienghene-Pouebo);
- a "customary sea" depending on a legendary underwater chiefdom from mythology (Belep);
- a remarkable feature of the landscape (e.g., fringing reef, outcrop, sand bank, large coral head, etc.) linked to an oral tradition (e.g., the tale of the Rat and Octopus in Tiga);
- a remarkable feature of the landscape associated with an ancient wave of migration (e.g., zone of the Pleiades Héo in Ouvéa which is linked to matrimonial ties with the Bouarate chiefdom of Hienghène);
- a distinct feature of the seascape associated with specific fishing rituals (e.g., Mangalia and Weyem passes for sharks between Hienghène and Touho). These areas are under the authority of clans that are identified and recognized by the Kanak society.

These few examples fundamentally mark the influence of the Kanak culture on areas that could be considered free of any human impact. The reefs near Grande Terre and the islands, or the barrier reef and passes between the reefs, are all known and symbolize Kanak pathways of both the living and the dead. For almost 3,000 years, the presence of the Kanak society on Grande Terre, together with the tragedies and victories of its people, have been imprinted on both their memories and the reefs themselves.

[18] *Jahma:* a type of oral tradition in the languages of Hienghène (Fwâi, Némi, Pijé, Jawé). It is often translated as "myth" because of the topics it deals with, where the origins of clans, pharmacopoeia, dance, etc. can be evoked. It can also attest to the representation of a political organization, of rules to be respected.

[19] *Huremeno:* literally "end of the journey" in the Fwâi language of Hienghène. This ritual is carried out on land as well as at sea when entering a space inhabited by men or spirits. It is carried out by the visitor who, stating his identity, presents an offering to his visible or invisible host.

[20] *Hiri ne buai:* literally "shouting forbidden", in the Fwâi language of Hienghène.

Chapter 30

Cultural, subsistence and commercial fisheries in reef ecosystems

Catherine Sabinot, Gilbert David, Matthieu Juncker, Séverine Bouard, Camille Fossier, Julie Mallet and Floriane Kombouare

Return from *mikwaa (Chanos chanos)* fishing, Isle of Pines. © J. Tikouré

For the inhabitants of New Caledonia, the reef is much more than a coral colony, a reef flat or a barrier reef. The reef encompasses the lagoon and its inhabitants, its passes, living beings, souls, stories and memory. For Kanak people, this space is both an invisible and a visible world. The invisible world is where the ancestors live, where the paths lead to the kingdom of the dead. The visible world is experienced and known through fishing practices, among the other things that make up the daily life of many on the "Pebble" ("Caillou" in French, the popular name of Grande Terre). Along the coastline, there is no village or tribe for which fishing is not important. These fishers are men and women, young and old and from diverse backgrounds. They fish for food, to maintain connections with their environment, to strengthen and renew ties between families, clans, and tribes or simply for recreation. Many New Caledonians have "grown up in fishing". Their parents were fishers who transferred their knowledge, their fishing techniques and, above, all, their passion for spending their time at sea.

The fishing practices and the importance of this activity for the inhabitants of New Caledonia raise so many questions that one book would not be enough to fully cover the topic: who is fishing and for what? Are there different fishing techniques? What are the target

Wood sculpture representing the head of a *mikwaa* (milkfish), Isle of Pines. © M. Juncker

species and the quantities collected? How do we know the species that inhabit the reef and their behavior? How do you build a "reef experience"? What is the importance of reefs for fishers from different backgrounds? How are fisheries organized in each territory? What are the social, cultural, symbolic and economic values of the New Caledonian reefs in the eyes of its inhabitants?

Researchers in anthropology, ethno-ecology, and geography are working on these questions. Several research projects have contributed to a better understanding of how New Caledonian people think about this environment and how they use it. This research offers a modest contribution from human and social sciences to characterize lagoon fishing and talk about the fishers who practice it, thereby revealing the importance of coral ecosystems for New Caledonians.

A fisher observes the lagoon, bay of Upi, Isle of Pines. © P.-A. Pantz

Knowing the reef and building fishing experiencer

For many, fishing is a common practice that requires careful observation. The experience is daily for some, regular or less common for others. Fishers know the reefs, they name them, they classify them. They also know how to decipher their environment and will choose a fishing spot according to tide, season, weather, etc. They acquired this field knowledge through the observation of the elders: "it is by going out to sea with the elders that we learn to fish". They scan the surface of the lagoon from the beach, from their boats, or even from the top of a pirogue mast to locate a school of fish or a particular species.

Observation is what every fisher talks about when he or she learns to fish: "First, I look." Fishers are very familiar with the reef and they use various "markers" to ensure good fishing.

- A sea krait swimming at the surface is sign of isolated reefs with fish;
- A flock of seabirds indicates the location of a school of fish;
- Unusual rippling of the water surface reveals the presence of pelagic fish;
- The massive stranding of small crustaceans in Prony Bay indicates the presence of schools of mackerels;
- After a tropical cyclone, large-eye seabreams, short-nose unicornfish and long-nosed emperor readily bite at the line, while Spanish mackerels dive deep into the depths.

"Below the terns there are anchovies, and therefore Spanish mackerels; below the petrels there are large sardines." (Koumac)

For many New Caledonians, fishing techniques are learned with the elders. The knowledge of fishing spots is shared by relatives and sometimes new ones are discovered after intensive searches: places where reef fish congregate, "lobster rocks", or "octopus caves", etc. Fishers know where the short-nose unicornfish are and when they are fat. They even observe changes in their behavior at sites regularly visited by fishers. Their observations also attest to the resource depletion or the disappearance of fish schools from sites where they were abundant in the past (rabbitfish, short-nose unicornfish, long-nosed emperors, groupers, etc.)

"There is less fish. Me, when I had the other tiny [tin boat] to myself, alone, I fill the icebox. Now, at five or six, we never fill the icebox." (Pouebo)

Box 24

From the knowledge of the elders to GPS

"I fish in relation to places, for fish, for crab, for everything. I use a GPS now... Before, our Elders, they didn't teach us with GPS, we used mountains for landmarks." (Koné)
"Before, our Elders, they show us the rocks [sic] but it was secret." (Koné)

GPS is an increasingly widespread instrument that is transforming the knowledge of places. It is valued by fishers, especially for those who go far offshore and it is defining new ways of communicating fishing grounds. In Bélep, for example, for young fishers targeting sea cucumbers, GPS makes it easier to explore new areas that had not been visited since their grandfathers with their sailing boats. It is a new tool that challenges the production of knowledge and its transfer to new generations.

The observations that fishers collect (passed on or learned) over years, decades and sometimes even generations, build up a "knowledge", a fine understanding of the reef and of the behavior of the organisms that inhabit it. Today, this knowledge is also of interest to marine biologists and ecologists because it assists them in locating migration corridors, identifying reef fish spawning periods and areas, etc.

Knowing where to fish and being respectful of each other's territories

"There are several of us fishing here. Here at home, among Kanaks, it's forbidden to cut in front of someone else, so we go to small places where there's no one." (Poum)

"When professional fishers came to work in the fishing business, it was done quite naturally. We [professional fishers] don't go on the reef flats, because it's dangerous enough to get close to it, but also out of respect for those who don't have boats, those who will walk to cast their nets or fish on the reef. It was done quite naturally: there was no meeting to organize fishing grounds, etc." (Lifou)

When you are a fisherman, whether you are Kanak or not, there are a number of implicit "rules" about how to use fishing grounds. The "first on the spot" rule is one of the most common. In addition, while barrier reefs and remote isolated reefs are privileged fishing grounds for boat-owners, especially professional fishers, reef flats and fishing grounds close to residential areas are reserved for subsistence fishers.

Fishers name both species and the places where they can find them. Toponymy thus applies to the seascape. Some islets are taboo and can be surrounded by mists so approaching them can be risky. Places that should not be visited are also named. For example, the small "Peto" Reef ("pillow" in Numéé language) in the south of Ouen Island, in the Southern Lagoon (Grand Lagon Sud) is a taboo reef. The reef is the pillow of the Wakôdô shark, guardian of the island, and must be preserved from any fishing.

Box 25

Taboos on fishing grounds

In New Caledonia, taboos on fishing grounds are numerous and diverse and they always imply a ban on access or removal. They may apply to all inhabitants of the island or only certain tribes or individuals. A clan or person may be entitled to temporarily remove these bans in order to organize, for example, a collective fishing trip for a particular event such as a wedding, investiture of a chief, yam celebration, etc. While the primary function of these bans is social, they also benefit the preservation of marine wildlife.

Tool selection according to location and type of practice

The type of fishing practice generally depends on where people live, their resources, their knowledge, their profession, their duties and so on. It is common for several tools to be taken on board the tiny (tin or light aluminum boat) to be able to adapt to the fish species available at the fishing site, or even to their behavior.

Reef flat fishing aims at collecting shellfish and octopus. While men are not absent from this fishery, it is mainly a fishing practice of women and children.

Angling is often carried out on the soft bottom of the lagoon, at the edge of a fringing reef flat with rising tide, or near isolated reefs for catching species living on the bottom, or close to the bottom, such as large-eye seabreams (Lethrinidae). It is carried out by both men and women.

Spear guns are used by young and old to target the most common reef fish (parrotfish, groupers, etc.) throughout the lagoon, from the coast to the barrier reef, in the passes and outside of the lagoon. Rock and slipper lobsters are caught by hand while free diving or using spear guns for the biggest specimens.

The tide is good, the net is ready to cast. The fisherman is looking for rabbitfish on a reef flat. Goro Bay, Yaté, 2009. © M. Juncker

Bare hand gathering, and free diving is also practiced for the collection of some shellfish such as trochus and giant clams, as well as holothurians (bêche-de-mer) for the Asian market.

Fishing nets, especially the seine and cast-net, are used for gregarious fish species that occur in shallow water (usually one to seven meters deep) such as the short-nose unicornfish *(Naso unicornis)*, rabbitfishes (Siganidae), mullets (Mugilidae) or white fishes (strongspine silver-biddy, milkfish or *Gerres longirostris*). Seines are often reserved for "experienced" fishers; young people usually fish with spear guns, troll or fishing lines, and children often start learning how to fish by hand on the reef flat and later with a fishing line from a boat.

Cast-net fishing, Brosse Islet, Isle of Pines. © P.-A. Pantz

Fishing to exist, trade, feed and sell

"Our field is on the reefs."

These words have been heard in various places in New Caledonia and refer to both current and ancient representations of the role of reefs in the lives of fishers, especially the clans of the sea. Knowing the importance of the field, and particularly the importance of yams for the Melanesians, we understand the value of this statement.

Fishing plays a fundamental role in the organization of Kanak societies. It reinforces the ties between clans through exchanges and is the identity of the fishing and sea clans: it is a duty they have to accomplish for the respect of their chiefdom and the other clans. The product of their fishing is handed out to the chiefdom or shared during customary ceremonies. Fishing is also important in non-Kanak societies, but in different ways. Being able to provide a guest with lobsters or certain large species is rewarding and for religious events, some fishers are relied upon for their catch.

«"I'm trying to keep fish in the freezer because we have people from the [mountain] chain coming by any time to get fish for customs up there." (Hienghène)
"Before, since I was a little girl, I used to fish on the reef flat with my parents. To make things better, I took a boat so that I could travel a little further. The first idea was to provide to those in the [mountain] chain: fish and trade with them. Instead of selling, we trade. […]. They make [give] us what is found [grows] in the range: taros, cassava…." (Gomen)
"There's xalaïa, donations for the pastor every first Monday of the month. If you don't have any coins, you bring fish; if you don't have rice or fish, you bring coins. Or yams, cassava, bananas." (Poum)

Fisher with a sagai and cast-net. Doueoulou, Lifou. © P.-A. Pantz

Fishing has a special place in the diet and daily life of New Caledonians. It is important to remember that the only sources of animal protein before the introduction of deer and pigs were birds (notou, kagu, etc.), flying foxes (bats) and marine resources. In 2011, a survey of people living in tribes[21] revealed that over half of the families living on customary land practiced fishing: 57 % of households had at least one fishing activity in 2010. A total of 2,730 tons of seafood products were taken from the reefs by the Kanak people living in tribes including lagoon fish, crabs, lobsters, shellfish, octopus, bêche-de-mer. On average, fishing represents 370 kg/year/household, with figures reaching 586 and 572 kg/year/household in Ouvéa and in tribes of the far north (Belep, Pouebo, Ouégoa, Poum and Kaala-Gomen), respectively.

Like in agriculture, seafood products are primarily used for self-consumption and donations (60% self-consumed, 19% donated in 2010) and 21% are sold. In 2010, fishing generated XFP 644 million in revenues for tribal populations. Households in the northern, western and southeastern tribes (Yaté, Thio and Isle of Pines) tend to sell their fish much more than those in the rest of the country. That same year, in addition to fisheries "mainly for subsistence", 656 tons of fish from the lagoon (538 tons in 2015), 2,860 tons of tuna and tuna-like species (2,840 tons in 2015) and 253 tons of sea cucumbers and trochus (192 tons in 2015) were officially taken from the New Caledonian reefs by professional fishers (as declared in the fishing logbooks filed with the provincial authorities). This resulted in sales of XFP 555 million in 2010 (XFP 447 million in 2015) for seafood products coming exclusively from the lagoon and XFP 1,300 million for longline fishery products (XFP 1,200 million in 2015).

"The lagoon is our larder"

***«"It's not just about nickel in this country... we cannot eat earth."* (Koumac)**

"There is no other choice but to value fishing or tourism, if we don't do it, soon there will be no one left in the islands, they will all leave. This is a way to keep people at home."

[21] Survey conducted by the IAC among 1,786 households, or about 12.5% of tribal inhabitants (GUYARD *et al.*, 2013).

Loading of a milkfish or *mïkwaa (Chanos chanos)* net on a decked pirogue in Pwadèwia, St. Joseph Bay, Isle of Pines, 2017. © M. Juncker

Circled by a net and then caught by strong fishers, the milkfish or *mïkwaa (Chanos chanos)* are brought back on board a pirogue, Isle of Pines, 2017. © B. Juncker

Fishing trips ("coups de pêche" in French), are valued by all New Caledonians who are attracted to the sea, as a way of feeding the family, contributing to ceremonies, earning a little money or even earning a larger income. We must remember that, above all, the lagoon is described as a "larder" by many women and men who live by the lagoon, near the reef flats. This term symbolizes both the food, economic and symbolic values attached to the reef and those who experience, know and want to care for it. It shows that, for many reasons, coral reefs are an essential natural and cultural heritage for New Caledonians.

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Chapter 31

Reefs invertebrates: sustainable resources for local populations in New Caledonia?

Pascal Dumas, Marc Léopold and Loïc Bourgine

In New Caledonia, the giant triton *(Charonia tritonis)* is used to gather or warn the inhabitants of a village. © ADCK/CCT/P.-A. Pantz

Octopus, shellfish and crustaceans... the great diversity of reef resources

The use of reef species by Pacific island populations is not new, as evidenced by the abundance and variety of fishing related artifacts (hooks, pirogues, tools, shellfish, etc.) found in the geological strata associated with the settlement of the Lapita populations in the region. Although the diets of coastal populations have diversified considerably since antiquity, these resources are still an essential component of the Pacific islands' food security and a central element of their cultural traditions.

While the diversity of harvestable reef species is high - almost 100 species in a typical South Pacific island about 30 years ago - the range of species that are actually taken from the environment varies widely according to geographical areas and their environmental, economic and cultural context. Studies show that island populations generally collect a large diversity of invertebrates, and that they particularly target bivalve mollusks (giant clams, cardium, oysters, mussels, clams, etc.), gastropods (trochus, green snails, cones, strombus, spider conch, etc.), cephalopods (octopus), crustaceans (crabs, shrimps, rock and slipper lobsters, hermit crabs - including the large coconut crab *Birgus latro*) and echinoderms (sea urchins and, more recently, holothurians). These artisanal practices usually operate at small

spatial scales (one or several adjacent reefs, an island, etc.) for subsistence, and have gradually evolved, for some species with high market value, towards commercial fisheries.

Most of the species are harvested primarily for consumption, sometimes after transiting through various traditional channels of exchange or sale. Some others are emblematic and still play a role in the social and cultural practices of the region. These species are, for example, the giant triton (*Charonia tritonis*, Triton's trumpet or "toutoute" in New Caledonia) used as a wind instrument for gathering or warning the inhabitants of a village; cowries or cones used to make seashell currencies; pearl oysters and giant clams used to embellish prestigious objects for customary exchange ceremonies, not to mention the many species used in jewelry or those that end up in craft markets for visitors.

Exploitation of reef resources in New Caledonia

In New Caledonia, as in many other islands in the region, coastal ecosystems - including coral reefs, mangroves and seagrass beds - contribute to food, income and, more importantly, to the self-sufficiency of coastal and island populations. In this respect, the territory benefits from particularly favorable conditions: over 4,500 km^2 of reefs with a high level of structural variability (fringing, intermediate, and barrier reefs - sometimes double or triple -, atoll reefs, etc.). Furthermore, the territory's location at the interface between tropical and temperate zones, means it is responsible for a wide variety of potential ecological niches for benthic species. With nearly 10,000 officially recorded marine invertebrate species, including more than 2,150 marine mollusks, 2,000 arthropods and 250 echinoderms, New Caledonia's coral reef ecosystems are

Coconut crabs *(Birgus latro)*, cooked and ready to eat. © P.-A. Pantz

Green snail *(Turbo marmoratus)*, Vanuatu. © IRD/P. Dumas

recognized as a "hotspot" of global biodiversity. A study carried out by the IRD revealed that over 60 species of macroinvertebrates - mainly mollusks - are harvested by fishers from the fringing reef flats around Nouméa (zone of Grand Nouméa). According to the available statistics, invertebrate catches frequently reach between 150 and 200 tons per year (excluding trochus shells), throughout the territory. However, these values are most certainly underestimated due to the informal and dispersed nature of these activities, particularly recreational and subsistence fishing, which makes them difficult to assess.

The majority of species are traditionally kept for local consumption, including mangrove crabs, lobsters, octopus, giant clams, and the numerous shellfish species collected at low tide such as clams (*Anadara scapha)*, ribbed Venus clams *(Gafrarium Tumidum)*, mussels (*Modiolus auriculatus*), tiger conch (Strombus luhuanus), and other spider conchs *(Lambis* spp.*)*. Others are exported, including holothurians (bêche-de-mer) and trochus, with a cumulative export value ranging between XFP 400 and 500 million/yr in recent years. Scallops *(Ylistrum japonicum)* have recently been added to the list of exports: they are highly sought-after for the quality and delicate flavor of their flesh and 30 tons were exported to the Asian markets in 2016.

Opportunistic overexploitation of sea cucumbers: a major challenge

The exploitation of holothurians (sea cucumbers) was developed in New Caledonia exclusively for the export of "bêche-de-mer" or "trepan" (the name of the product once the animal has been eviscerated, boiled and dried) to Asian markets. As in neighboring countries, fishing for sea cucumbers began in the early 19th century with commercial expeditions establishing precarious and temporary installations in isolated fishing areas. However, globalization and the boom in demand from the Chinese market since the 1980s have had a profound and lasting impact on exploitation throughout the Pacific.

Sea cucumber (bêche-de-mer, Holothuria atra), New Caledonia. © IRD/P. Dumas

Many countries have put in place national moratoria following the rapid collapse of catches after a short development period in these fisheries. Sea cucumbers are very easily collected by hand in shallow waters, or by free-diving, and are therefore very vulnerable to fishing. In the absence of effective restrictions, intensive exploitation of spawners generally leads to a depletion of the resource in 10 to 20 years, or even less for high-value species such as the sandfish *(Holothuria scabra)*, white teatfish *(H. fuscogilva)* and black teatfish *(H. whitmaei).*

Unlike its neighbors, New Caledonia was relatively spared from overexploitation until 2010. Fishing is restricted to less than ten species and is limited to the western and northern lagoons, the coastal reef flats and the barrier reef down to 20 meters (the use of scuba gear or compressors is also prohibited). Catch varies between a few tens and a hundred tons of bêche-de-mer per year and is a source of income for more than 200 professional fishers (export value in 2016: XFP 425 million). However, the country is now facing major market pressure, which threatens the sustainability of these fisheries and requires authorities to rapidly adapt regulations (especially the effective implementation of minimum catch sizes and fishing licenses). A system of co-management by quota was successfully developed by provincial and customary authorities as well as fishers in a pilot project, but its large-scale implementation poses difficulties. Sandfish aquaculture is another development alternative that has been experimented over the last ten years. Restocking trials of this species are underway since 2014, but they produced mixed results. It is not yet possible to consider such operations as a remedy for overexploitation because they are expensive, and their success is uncertain.

The steady exploitation of trochus

Like giant tritons, helmet shells, tiger conchs and other cowries, the trochus *(Tectus niloticus)* is a marine gastropod mollusk found on coral reefs in the Indo-Pacific region. Trochus build fairly large shells (the largest specimens are over 15 cm in diameter), which are highly sought-after for the quality of their nacre or mother-of-pearl layer, exported from the beginning of the 20th century to Europe and Asia for the luxury button industry and artisanal jewelry. Its high value and non-perishable quality (shells can be stored for several months before being sold) make it an attractive source of income for isolated island communities.

As a result of its rapid geographical expansion in the Pacific from translocations carried out in the 1930s and 1940s, growing demand on the world market soon raised serious concerns about resource sustainability. Despite increasingly restrictive fishing regulations and improved measures for restocking from aquaculture, trochus is overfished in the majority of Pacific countries. This generally results in stock decline, which can even lead to local extirpation in some regions.

In New Caledonia, trochus exploitation began in the 1900s and exports soon peaked at around 1,000 tons of shells per year between 1910 and 1920. After a sharp fall in activity during the Second World War, the first regulations were introduced in the 1950s to protect a resource whose vulnerability was detected by scientists. Trochus individuals have a highly heterogeneous spatial distribution: they are not randomly distributed on the reefs but aggregate in very specific and rather accessible "microhabitats" (particularly eroded hard bottoms on reef flats and reef crests with low structural complexity and low coral cover).

Although its rapid growth and early sexual maturity makes it relatively resilient, trochus is particularly vulnerable to overfishing, especially since they move slowly. In New Caledonia, however, the resource does not seem to be threatened in the short term. With a decline in demand for mother-of-pearl in favor of synthetic materials, trochus is no longer actively sought-after: volumes exported in the last 10 years range from 150 to 200 tons per year for a turnover of between XFP 40 and 80 million, far behind that of reef fish catches. In addition to a catch size limit set between 9 and 12 cm to protect the reproductive potential of the species, the management of this resource benefits from the existence of numerous marine reserves distributed throughout the territory.

With diverse status (marine protected areas, sustainable resource management areas, customary reserves, etc.), these protected areas can be considered as refuges for broodstock, and therefore eventually support the regeneration of impoverished populations in the surrounding areas. A recent study indicates that adult trochus populations are twice as dense within the marine protected areas of the Southwestern Lagoon, and that they are made up of specimens 10 to 20% larger, on average, than those observed in the surrounding fished areas.

Very similar results are observed in neighboring Vanuatu, where reserves have very different characteristics (size, regulation,

governance regime). In addition to protection and status, the effectiveness of marine reserves to maintain or restore heavily exploited populations mostly depends on the presence of suitable environmental conditions: for trochus and other benthic species that are highly dependent on substratum, resource management cannot be planned independently of habitat characteristics.

Harvesting mangrove crab for the local market

In New Caledonia, as in other Pacific islands, mangrove crab *(Scylla serrata)* is a major resource for the populations living near mangroves. Catches have increased steadily in recent decades to exceed 40,000 tons throughout the entire Pacific region. On the west and north coast of New Caledonia, the mangrove crab fishery gradually evolved from an active subsistence and traditional fishery to a commercial fishery, following the introduction of more sophisticated fishing techniques (such as folding traps) in the early 2000s. Mangrove crab catches doubled in the last 10 years, from about 20 tons (as officially declared) in 2006, to over 40 tons in 2015, with a peak of nearly 80 tons in 2010. However, these figures represent only part of the reality: a study conducted by the IRD revealed the importance of the catch sold in the municipality of Voh, which alone reached nearly 100 tons of crab in 2006.

Due to its socio-cultural and economic importance, the sustainable management of this resource is a real challenge: the first regulation governing the crab fishery dates back to 1963, and already established a minimum catch size and a temporary (two-year) ban on catching soft-shell crabs (i.e., during the molting period[22]). Substantial research efforts on the biology, ecology and prospects for aquaculture of the species in New Caledonia have since led to changes in regulations, which are currently based on four main measures:

– an annual closure of the fishery between December 1st and January 31st, during which any form of capture is strictly prohibited, in order to protect individuals during the peak breeding season of the species;
– a legal catch size of 14 cm (total width of the animal) aimed at limiting fishing pressure on individuals which have not yet spawned;
– a total ban on the consumption or sale of soft-shell crabs, and the marketing of crabs other than whole living crabs (crabmeat is prohibited, with special exceptions);[23]
– a ban on crab traps with a mesh size smaller than 65 mm.

As a result of these measures, the resource does not currently show signs of overexploitation throughout the territory.

While the biology of the species is now well known, some gaps in our knowledge - including the difficulty of observing and capturing juveniles in their natural habitat - still hamper our detailed understanding of how harvesting affects stocks. Some studies also highlight the marked variability in catch rates at small spatial scales (kilometers), given that legal-sized crab densities may vary by more than one order of magnitude between different habitats. From one mangrove to another, fishing can be less productive, particularly in areas where sedimentary conditions, salinity, temperature, vegetation cover, etc., will naturally be less favorable to the species. This highly heterogeneous distribution of the resource has strong socio-economic implications in New Caledonia, where customary land tenure generally prevents fishers from freely selecting their fishing areas. As in other Pacific countries, they depend mainly on traditional access rights rather than on the actual availability of the resource. Even if this practice evolves with the modernization of fishing techniques and the development of on-board fishing, these informal rules largely determine the areas accessible to fishers. These results highlight the importance of a conservation strategy that encompasses habitat, particularly at small spatial scales; they also raise questions about New Caledonia's fishery regulations and the optimal management of such a spatially heterogeneous resource. The congruence between ecological scales (shaping the natural structure of populations) and harvest scales (structuring fishing activities) is thus a strong argument in favor of the spatial management of mud crab fisheries.

[22] *Arrêté du Journal officiel de la Nouvelle-Calédonie,* June 25th 1963.

[23] "Fishing, transportation, marketing, display for sale, sale and purchase of mangrove crabs are prohibited from December 1st to January 31st. Fishing, transportation marketing, display for sale, sale and purchase, possession and consumption of soft-shell crabs and crabs smaller than 14 cm in the largest dimension are prohibited at all times. Only live whole crab may be marketed. The display for commercial purposes of crabmeat in any form whatsoever is prohibited at all times, except exclusively for restaurateurs and caterers, and only in the premises where they carry on their activity, which are certified or approved for hygienic purposes" *(Extract from the North Province Fishery regulations, 2006).*

Mud crab or mangrove crab *(Scylla serrata)* ready for sale, New Caledonia. © P.-A. Pantz

While the decline of reef resources is a global issue, it is of particular significance to the islands of the Pacific region. In fact, the vast majority of macrobenthic reef species are of interest to fisheries at some point in their life cycle: their depletion represents a major risk for the economy and the livelihoods of coastal populations, whose dependence on seafood products is generally inversely proportional to the level of economic development. The implementation of a fishery policy for the sustainable management of coastal ecosystems and their resources is a major challenge for New Caledonia, given the current economic context which is deeply affected by the nickel crisis and the political challenges of the future.

Chapter 32

Natural substances: hidden treasures

Sylvain Petek

Gorgonians and alcyonaria are among the organisms tested for biological activities. © IRD/S. Andréfouët

For most people, "natural substances" are closely associated with traditional medicines, ethnopharmacology, herbal medicine and even aromatherapy. This association of ideas comes from multi-century-old knowledge of the uses, mainly of terrestrial plants, in curing various diseases in different communities around the world. Behind this notion, lies a more general interest in molecules synthesized by organisms, particularly those with specific biological and/or therapeutic activities.

Regardless of the organism under consideration, the molecules it produces are generally classified into two groups: those essential to life, known as primary metabolites (amino acids, nucleotide [ADN, RNA...], fatty acids with membrane function, etc.) that are found in very different taxonomic groups of organisms; and those known as secondary which are not involved in fundamental physiological functions, and are generally specific to the type of organism considered (plants, bacteria, fungi, etc.). The latter will be the focus of the present chapter.

From chemical ecology to applications inspired by nature

During evolution, organisms have developed a whole range of secondary metabolites for adapting to the physical (luminosity, temperature, pressure, salinity, etc.) or biological (predation, colonization, infestation, etc.) variations of their environment, and to communicate. Transdisciplinary studies of chemical ecology, involving both chemists and biologists, make it possible to isolate, identify and understand the role of these compounds. Thanks to this work, innovative, nature-inspired and more environmentally friendly solutions can be developed, whether in the realms of human and animal health, agronomy, aquaculture or other technological sectors.

Medicines from the sea

Although the use of terrestrial plants is a very old practice and widespread throughout the world in the various pharmacopoeias, the historical use of marine organisms is mainly known from China and the Far East. The Chinese Pen Ts'ao, published 2,800 B.C., contains a chapter exclusively dedicated to the use of algae for the treatment of gastric ulcers or goiter, for example. Much more recently, the Japanese have used a red alga, called *kaïniso (Digenea simplex)*, containing kainic acid, as an anthelmintic (antiparasitic), which has led to the preparation of a proper drug against *Ascaris*. Outside this geographical area, there is hardly any oral tradition or traditional medicine referring to the use of marine organisms.

It was from the mid-20th century onwards, with the development of new tools for underwater exploration and analysis, and especially from the 1970s, that systematic studies of marine biodiversity for uses in human health really began.

Life appeared in the oceans and they therefore still harbor all existing life forms. Of the 33 main lineages, 12 are exclusively marine and others are essentially marine (sponges or cnidarians [jellyfish], etc. of which there are a few freshwater species) - in other words, there is a whole range of marine biodiversity that is unparalleled in terrestrial and freshwater environments. In addition, seawater contains chemicals such as halogens (chlorine, bromine, iodine, fluorine), sulfur and metals that are not readily available elsewhere. This biological diversity, combined with the chemical specificities of the marine environment and the first encouraging discoveries, gives rise to many hopes for the emergence of a new marine pharmacopoeia.

For instance, the first cephalosporins, a family of antibiotics widely used today, were discovered in Italy in 1948, with the cultivation of *Cephalosporium acremonium*, a microscopic fungus found in lagoon sediments. The family of Arabinosides, with anticancer and antiviral properties, was inspired by isolated compounds of a Caribbean sponge, *Cryptotethya crypta*, in the 1950s.

Faced with this extraordinary biodiversity and without ethnopharmacological knowledge to guide them, the task of researchers is immense. In an attempt to select the most promising organisms, in situ observation of their behavior can provide some information. For example, organisms without physical protection that are not suffering from epibiosis, predation or grazing are likely to have developed a chemical cocktail designed for their defense. To study these organisms, different approaches have been used. Some are rather "systematic" (Fig. 1), without preconceptions as to the biological activity of the organism and with bioassays being carried out on isolated molecules. Others use bioguidance (Fig. 2), which first involves the selection of organisms based on their activity on a biological target (bacteria, enzymes, cancer cells, etc.) and the progressive isolation of the active substance(s) responsible for the observed activity. Each approach has its advantages and disadvantages.

After more than 50 years of research, a true marine chemodiversity has been discovered, with about 29,600 molecules isolated to date, a large part of which has no terrestrial equivalent.

As shown in Figure 3, just over one-third of the compounds are derived from sponges and/or their associated microbiomes. These sessile animals (chap. 13), unable to escape their predators, have

developed a "chemical arsenal" for their defense, for colonizing new areas and protecting themselves against pathogens. In addition, sponges belong to a lineage whose compounds provide the widest spectrum of biological activities: antibiotic/antibacterial, antifungal, anticancer, anti-inflammatory, antiviral, antimalarial, immunostimulant, antispasmodic, etc.

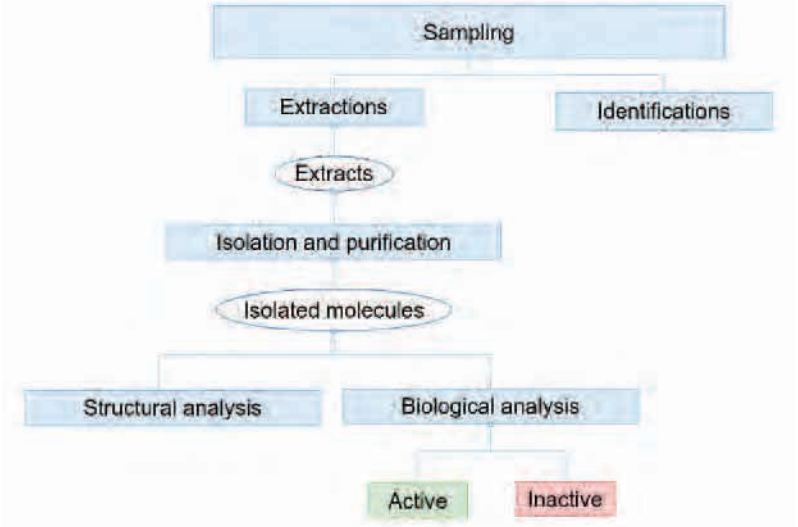

Figure 1: The "systematic" approach. © IRD/S. Petek

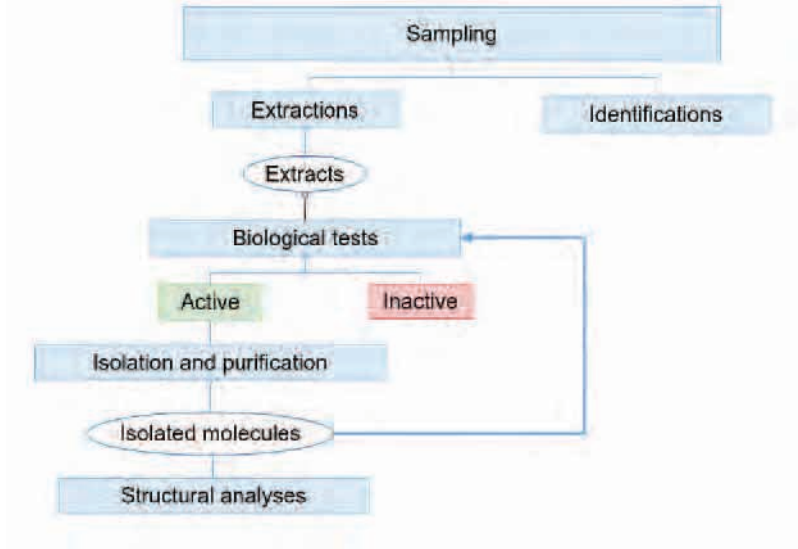

Figure 2: The "bioguided" approach. © IRD/S. Petek

Currently, in addition to cephalosporins (antibiotics, 5th generation since 1964), nine drugs of marine origin (or derivatives) have been placed on the market for anti-cancer, antiviral, analgesic and antiparasitic treatments. Some fifteen other molecules are being used in clinical trial assays. These figures may seem small in terms of the number of molecules discovered, but they are actually relatively significant. This is because, in pharmaceutical research, only one molecule out of every 10,000 will become a drug and it takes an average of 12 years between the discovery of the molecule and its launch on the market.

The valorization of marine natural substances often faces challenges related to resource access, availability and the environmental impact of industrial exploitation. Consequently, their use often involves the development of their synthesis by chemical and/or biotechnological methods or the production of simpler derivatives, where the aim is to keep only those fragments of the molecule necessary for the activity. This can also involve the addition of other functions which will provide complementary qualities in terms of assimilation, stability or target, known as pharmacomodulation. In this context, natural marine substances will be a source of inspiration for the discovery of original bio-active chemical structures rather than a resource as such.

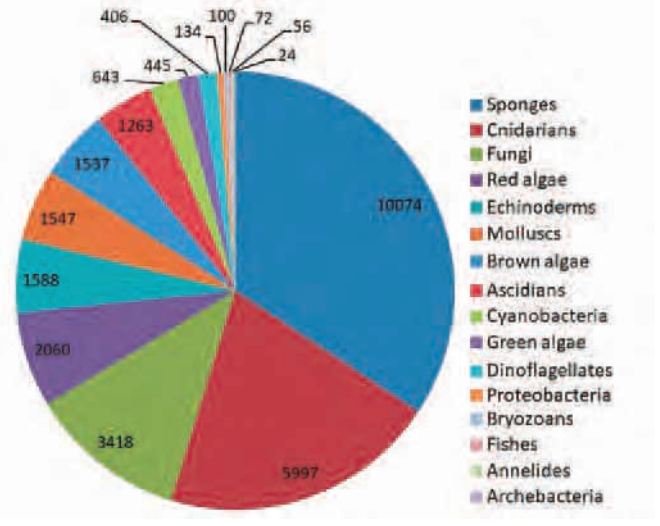

Figure 3: Distribution of molecules discovered by lineage. © IRD/S. Petek

Box 26

Cantharella, a database to capitalize natural substances

Sylvain Petek and Adrien Cheype

When we want to study natural substances[24], whatever their origin, we soon find ourselves confronted with managing a large volume of data of diverse natures and origins:
– sampling sites: country, locality, GPS point, species inventory, environmental/biotope information, etc.;
– taxonomic identification of the sampled organisms, their abundance, physical and genetic characteristics, etc.;
– chemical protocols implemented, molecules identified;
– biological activity assays performed.
In addition, these studies are multidisciplinary and require the support of many specialized collaborators, who are often geographically distant.

In the end, only part of this information will be included in scientific publications and thus permanently recorded. In the long run, therefore, there is a risk that the "raw" data may become unusable or disappear when it could provide historical records and serve as a basis for new projects. In addition, over time, the heterogeneity of paper or computer media, file formats, or the way data is structured make it very difficult to reuse information efficiently.

Cantharella (PETEK and CHEYPE, s.d.), a database dedicated to the study of natural substances has been designed to provide a solution to the various challenges arising from these data, in terms of:
– access and sharing between collaborators or transfer to collectivities;
– analysis and updating;
– long-term sustainability.

This collaborative tool, accessible online and developed from "free" software packages, uses four specialized modules to capitalize all the data from the field collection of organisms through biological assays to identified molecules.

In addition, as part of the Access and Benefit-sharing process (ABS, Nagoya Protocol), the tool provides a platform for the transfer of results to communities, who can thus monitor the research that is being done on their biodiversity. For universities or laboratories wishing to use it, the software is made available under a free license (https://forge.codelutin.com/projects/cantharella).

The IRD's instance of Cantharella, operational since 2010, is capitalizing on data from numerous projects, mainly in the Pacific (about 700 sampling sites and 950 species, and over 7,700 bioassay results).

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Explorations of New Caledonia's marine chemodiversity

In New Caledonia, the first marine bioprospecting studies targeting new molecules of therapeutic interest began in 1976 at ORSTOM with the research program Snom (Substances naturelles d'origine marine). This program was led by Pierre Potier (Institute of chemistry of natural substances, CNRS) and involved researchers and scientific divers from the IRD (ex-ORSTOM) and the taxonomic expertise of MNHN. Over the years, numerous other explorations, studies and research programs have been conducted, which involved several French and international multidisciplinary collaborations (Fig. 4).

A wide diversity of geographical zones, environments and habitats has been explored: from Grande Terre to the Loyalty Islands, the Isle of Pines, remote atolls and reefs (d'Entrecasteaux and Chesterfield), from lagoons to outer slopes of barrier reef, or seamounts (chap. 2).

Currently, out of all lineages, ranging from micro- to macro-organisms, biological analyses and/or activity assays have been carried out on a total of 9,372 species. Extensive pharmacochemical studies on about 50 organisms have isolated and identified more than 350 new bioactive molecules with original structures, including over 100 from sponges.

A few emblematic examples

Girolline, a tiny molecule extracted from *Cymbastella cantharella*, a sponge living on the outer slope of the southern barrier reef, was found to be particularly active during in vitro and in vivo assays on cancer and tumor cells. Without exhibiting major toxicity in mice and dogs, clinical studies were conducted up to phase II with the pharmaceutical company Rhône-Poulenc Rorer (now Sanofi-Aventis), before being interrupted due to side effects on the cardiovascular system. In addition, girolline has demonstrated interesting antiplasmodic activities *in vitro* on four strains of *Plasmodium falciparum*, particularly in synergy with chloroquine, paving the way for new antimalarial strategies.

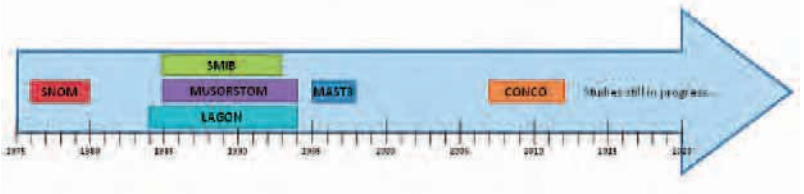
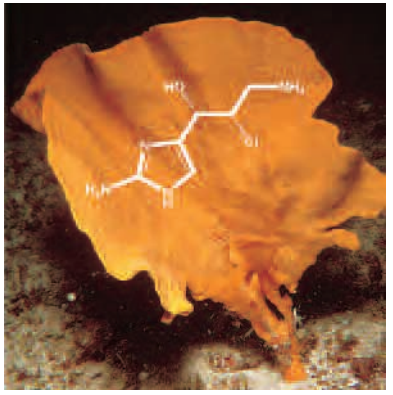
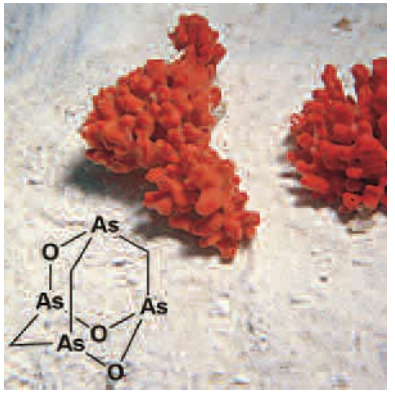


Figure 4: Main bioprospecting and therapeutically oriented research programs. © IRD/S. Petek

Laticauda Laticaudata and the erabutoxin b formula. © IRD/P. Laboute


The sponge *Cymbastella cantharella* and the girolline formula. © IRD/J.-L. Menou



The sponge *Echinochalina bargibanti* and the arsenicin A formula. © IRD/G.Bargibant

Arsenicin A, produced by *Echinochalina bargibanti*, a sponge from the eastern lagoon of Grande Terre, is distinguished by its nested polycyclic formula with four arsenic atoms, which is very unusual for an organic molecule of natural origin. It has bactericidal, fungicidal and antiproliferative properties on acute promyelocytic leukemia cells, as well as on pancreatic adenocarcinomas and glioblastomas.

The crinoid *Gymnocrinus richeri* and the gymnochrome B formula. © IRD/P. Laboute

The crinoid *Gymnocrinus richeri*, an echinoderm considered living fossil and sampled at a depth of 520 m on the Norfolk Ridge, led to the discovery of a new family of pigments: the gymnochromes, which have antiviral, anti-HIV and anti-dengue properties.

Poisonous cones, mollusks that paralyze their prey by injecting them with a mixture of neurotoxic peptides, are particularly promising for the discovery of powerful analgesics, such as Prialt® (1,000 times more powerful than morphine). A full research program is dedicated to the study of the genome and venom composition of *Conus consors* from the Chesterfield Reefs.

Lastly, the very emblematic sea kraits, *Laticauda colubrina* and *Laticauda laticaudata*, belonging to the same family as cobras or mambas (Elapidae) produce a particularly potent venom of which the polypeptide erabutoxin b, one of its main components, has been studied for its effects on the neurological system.

After all these years, only part of the pharmacochemical potential of the marine biodiversity of New Caledonia has been extensively studied (sponges, cnidarians, ascidians, etc.). The potential bioactive molecules of other biological groups and species have yet to be explored, rediscovered or valorized using recently developed biological and chemical techniques. Biotechnological developments involving micro-organisms are very promising in various scientific domains, such as microalgae for the production of biofuels or high added-value compounds for cosmetics or nutraceuticals.

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Chapter 33

The lagoon: a natural heritage and recreational space

Charles Gonson, Jocelyne Ferraris, Dominique Pelletier and Isabelle Jollit

Amédée Islet, a very touristic lagoon location. © P.-A. Pantz

Recreational uses: a challenge for coral reef management

"Recreational users" are defined as a group of people who engage in an activity for their leisure only, with no subsistence need or profit motive. These activities are characterized by a diversity of practices and under the influence of population growth and the development of tourism, their number in natural areas is increasing sharply. As is the case in New Caledonia, one of the world's largest lagoons listed as a UNESCO World Heritage Site in 2008, recreational use is intensifying and diversifying in all coastal areas.

Recreational activities such as fishing, scuba diving and water sports play at least two roles:

– an economic role by boosting a pool of activities through tourism or the boating industry;

– a social role in providing goods and services to people.

At the same time, they affect coral reef ecosystems that are already threatened by global climate changes. It is therefore essential to consider recreational uses in the sustainable development of coastal zones, particularly in island environments. Scientific studies have focused on the diversity of recreational activities in marine and

coastal environments (diving, boating, water sports) since the year 2000. This research was motivated by the growing need for knowledge and the complexity of the relations between a prolific society and the natural world, on which it depends, which is also a limited resource, and which is particularly fragile in coral reef environments. Research aims at better understanding socio-ecosystems to assist the management of these areas, notably through the establishment of Marine Protected Areas (MPAs). Within these MPAs, which have objectives as diverse as biodiversity conservation and sustainable use, recreational activities are widely practiced. It is therefore essential to improve the understanding of these activities not only just to ensure the protection of ecosystems and the resources that they depend on, but also to anticipate the emergence of conflicts for space occupation and resource exploitation.

However, recreational users are still not well understood. This is mainly due to the difficulty of designing appropriate methodologies and tools that ensure the reliable collection of information, over time, on their number, location and practices. In New Caledonia, research has led to the development of methods for assessing the pressures and impacts of these uses. These methods are adapted to the coral reef environment and allow the acquisition of knowledge useful to the preservation of lagoon ecosystems that are managed by a network of MPAs.

Recreational uses: research for sustainable development

The promotion of the natural heritage of coral ecosystems and their conservation is a real challenge for the sustainable development of New Caledonia. First, the increasing demographics, and then the development of boating and tourism, have led to recreational activities being considered a threat to the sustainable management of fisheries resources and the conservation of reefs. These uses are not well known and are difficult to quantify because of their scattered and informal nature. This is why, since the 1990s, research programs and projects have involved local stakeholders, environmental managers and scientists.

Scientific studies first focused on improving the assessment of pressures and impacts of small-scale coastal fisheries (commercial, subsistence, recreational). In 2005, catches by recreational fishers on motorized boats were estimated at more than 1,100 tons/year in the Southwest Lagoon. Made up mainly of fish and shellfish species, these catches are concentrated on reefs near urban centers (Nouméa and Koné) and in the northern and southern lagoons of Grande Terre. Findings highlighted the importance of studying recreational fishing.

Survey of a recreational fisherman at Pandanus Islet in 2014. © IFREMER/C. Gonson

Cruise ship anchored at Lifou. © IFREMER/D. Pelletier

Conflictual cohabitation between users in the anchorage zone of an islet.
© IFREMER/C. Gonson

Larégnère Islet under heavy traffic. © IFREMER/C. Gonson

Subsequently, because of the issues and costs associated with the complex management of lagoon uses, the substantial development of other activities, such as boating, diving and island excursions raised concerns among public authorities and research organizations. With the improvement of knowledge on coral reef recreational uses, the complexity of the coastal systems under study (the diversity of recreational activities, ecosystems and their connections) is becoming better reflected in research projects. The concept of a socio-ecosystem is increasingly important, including the development of multidisciplinary and spatially explicit approaches.

Recreational activities associated with coral reefs are now better known. This knowledge supports the effectiveness of the management strategies that are implemented for a variety of objectives such as resource management, biodiversity conservation and sustainable use. In the New Caledonian Lagoon, particularly within MPAs and UNESCO World Heritage sites, numerous research programs and management measures (e.g., regulations, awareness-raising) have targeted recreational uses. However, historical knowledge of these uses is limited. In addition, the rapid changes in these uses (e.g., diversification of activities, expansion of tourism), which coincide with global climate change, threaten the sustainable development of New Caledonia's maritime space.

The lagoon under surveillance: an explosion in the number of boats

In the Southwestern Lagoon, close to Nouméa, a large population converges with numerous nautical infrastructures. Promoting the natural heritage associated with coral reefs while protecting ecosystems close to urban centers is a major management challenge for New Caledonia. In this area, studies involving researchers and environmental managers have led to the development of observation protocols and indicators relevant to the monitoring of uses, their impacts and governance issues.

Between 2005 and 2013, nearly 700 field trips and over 2,000 questionnaires were carried out to estimate the number, attendance and spatial and temporal distribution of recreational users, as well as

to characterize their practices and opinions regarding the management and ecological state of ecosystems. Today, the methods for observation and the production of indicators have been optimized. Fully operational, they can now be implemented by environmental managers in New Caledonia, such as the provincial authorities and local management committees of UNESCO World Heritage sites.

During this period of less than 10 years (2005 to 2013), the number of boats visiting the reefs and islets around Nouméa more than doubled. These are mainly residents of the Nouméa agglomeration (Grand Nouméa), with at least 10 new boats joining the recreational fleet each week. In addition, the development of taxi-boats as led to an increase in the number of people visiting islets. For example, in 2013, it is estimated that over 10,000 boats and 80,000 people travelled to Maître Islet, and other islets located very close to Nouméa.

The activities are diverse and influence the occupation of the coastline by users in relation to the regulations and to the natural and social characteristics of the areas they use. The development of infrastructures (e.g., Maître Islet) can be used to attract large numbers of visitors, where specific activities (such as kitesurfing) are carried out. Protected natural areas, aimed at the conservation of species and natural habitats, with simple but attractive facilities such as moorings or shelters, are also popular because people expect high environmental standards (e.g., Signal Islet). In contrast, unregulated and often more remote areas tend to be targeted by boaters who want to fish and enjoy quiet islets that are less visited.

Based on the information collected, a simulation model aimed at promoting the adaptive management of lagoon areas, was used to assess the effect of management measures on the evolution of biodiversity and its uses. Results indicate that the development of alternative recreational areas (for example by providing parking lots or navigation buoys and markers) in coastal zones that are less vulnerable to the pressures associated with recreational activities (e.g., sand beaches) could limit the impacts on reefs and islets by draining part of the lagoon's users.

Sustainable recreational uses for a lagoon under pressure

The sustainability of coral ecosystems and their recreational uses depends on several variables, including ecological and social factors: ecological, because ecosystems suffer impacts that depend on their vulnerability to user activities and behavior; social, because the sustainability of uses also depends on whether people are satisfied with their experience of the lagoon. This satisfaction is particularly dependent on their ability to tolerate the presence of other people, in large numbers and in the same space, and their ability to practice their activities.

The distribution of users is increasingly heterogeneous, depending on the area and the time of year or week. Visitor peaks are now more frequent, and the associated pressures are also more intense, impacting very localized areas such as islands and reefs closest to coastal accesses. These pressures result in ecological impacts that alter the state of ecosystems, by the depletion or even extinction of the most sensitive species and habitats, and the modification of fish and invertebrate populations. However, the ecological quality of reef ecosystems also contributes to the sustainability of recreational activities, such as scuba diving or the simple enjoyment of coral reef seascapes. Users are increasingly aware of the impact of their activity on the ecological integrity of their environment. This awareness promotes environmentally friendly practices and thus the sustainability of reef socio-ecosystems. Unfortunately, the biodiversity of coral reefs is vulnerable to any form of human presence, and the state of coral reefs is threatened by the continuous increase in numbers of recreational users.

Beyond ecological sustainability, the intense use of an area can result in conflicts, either in the case of a single activity such as simply relaxing on very busy beaches, or because of the incompatibility between two practices, generally between fishing and water sports, or between boating and swimming, and jet-skiing. Public authorities have a significant role to play in ensuring the cohabitation of users for whom the overcrowding of the visited sites is an important

disturbance factor. Strategies for this could include the distribution of different activities over time and space, or the possibility of a "wilderness experience" although this would also increase visitor numbers to a certain extent.

Future research related to development issues

In the areas where it can be assessed in New Caledonia, the level of pressures due to recreational uses may seem relatively low in comparison with other regions of the world. However, it is part of a rapidly changing demographic and tourist context and involves ecosystems that are particularly fragile and vulnerable to climate change (more frequent and intense tropical cyclones, warming of seawater, coral bleaching, etc.). The threats to coral ecosystems and the sustainability of their uses are therefore real and growing. Yet, the real magnitude of the cumulative effects of all these pressures on the state of the ecosystem and its functioning is poorly assessed because of their complexity. This is particularly true in the case of the effects of climate change or in lagoons facing anthropized zones, where the increase in pressures associated with recreational activities coincides with an increase in pressures from land-based sources.

In addition, recreational uses should be monitored in areas where strong demographic or tourist developments are taking place, or are expected, in order to better understand their impacts and evolution. These include the Koné region which has undergone recent economic development or the Loyalty Islands where cruise tourism is booming. The assessment of the ecosystem's state of health must be compared to the pattern of activities in order to identify the most vulnerable areas. This will involve identifying limits to practices based on the vulnerabilities of the surrounding environment. There is also a need to better understand the nature and motivations of users, in order to anticipate changes in their behavior following the introduction of new management measures that may modify their practices (e.g., shifting fishing effort out of the MPAs).

A better understanding of lagoon socio-ecosystems implies the consideration of an appropriate geographical scale. In New Caledonia, due to the mobility of users, their interactions, the connectivity of ecosystems and also the diversity of the structures of environmental management, the entire New Caledonian territory must be taken into account. At this scale, harnessing the knowledge and expertise in a multidisciplinary approach that combines environmental sciences and the human and social sciences - disseminated to decision-makers and civil society - should enhance the anticipation of the environmental and economic consequences of development policies.

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