Partie 5

# Vulnerable species in a fragile environment

## Management, protection and conservation

*Coordinator: Eric Vidal*

*Managing, protecting or conserving coral reefs involves several considerations. Is it about managing an environment, a resource or a territory? Is it to preserve a rare or threatened species or to maintain essential ecological processes? Is it to ensure that everyone continues to live and enjoy the reefs, to fish and observe marine life? Or is it to safeguard the stories and myths that are associated with it and contribute to the identity of each person? Here, the combined views of biologists, anthropologists and environmental managers prove that managing reefs involves the consideration of different knowledge, values and uses, which are essential to recognize, reconcile and engage in dialogue to establish shared rules.*

*Chapter 34*

# Managing emblematic species and reef ecosystems

*Catherine Sabinot and Éric Vidal*

Humpback whale tail *(Megaptera novaeangliae)* belonging to an endangered population that is breeding in New Caledonian waters. © Opérations Cétacés/C. Garrigue

Many biologists who work in New Caledonia have offered to contribute to this book on New Caledonia's coral reefs by presenting the species they are focusing their research on and which, according to them, justify specific management measures.

These chapters will therefore showcase a few species that are of particular interest to scientists in New Caledonia. Some of them describe the knowledge that scientists have accumulated on these animals and tell us how this knowledge can inform or has already guided coral reef management and conservation policies. These species are not only studied because they are emblematic or charismatic. They can be valuable bio-indicators of the state of the ecosystem, or they can be "sentinel" species that can reveal subtle changes in the environment at an early stage. Others play a special role in the ecosystem, and many other species and habitats can rely on them. For example, seabirds form dense colonies that fertilize terrestrial and marine ecosystems with their feces. Some of these charismatic species can also be labelled "flagship species", and the public and users are more inclined to accept restrictions and regulations to guarantee the conditions of their protection.

Research in human and social sciences aimed, among other things, at documenting the views of New Caledonian people

on emblematic marine animals, was initiated recently. Some aspects of this are shared in the inset boxes, where the species chosen by biologists can be found; however, the emblematic status of a species is mainly justified by its social and symbolic significance. This reminds us that taking into account the social values of species as well as local and scientific knowledge is always a major challenge when building integrated, and respected, management policies.

In the following pages, the authors will therefore give priority to each "species" itself. However, this is not to lose sight of the challenges (as shown in other chapters of the book) faced by authorities to plan, structure and organize management and conservation policies with an ecosystemic and spatialized vision of the lagoon space which is to be preserved. It is also for this reason that this book has given special importance to the collectivities in charge of the different types of reserves and protected areas.

*Box 27*

**What are the emblematic reef species for New Caledonians?**

*Camille Fossier, Estienne Rodary, Gilbert David, Espérance Cillauren, Ambre Piémontois and Catherine Sabinot*

The ESPAM program is interested in the emblematic species, social acceptance and the sustainability of marine protected areas. In 2017, it began important work on emblematic marine animals for New Caledonians. The objective of this project was to find out which species are the most important for the inhabitants of the island by collecting a list of these species from them, including the reasons for their choices.

A first significant result was the diversity of the species mentioned: out of seven public meetings, 80 species were mentioned. Of these, turtles, sharks and dugongs were the most frequently named, but the species that are fished for food were also important.

A second quite remarkable observation was the reasons why these animals are seen as emblematic. The social and symbolic importance of animals (culture, Kanak totem, etc.) is the most widely mentioned reason, followed by the enjoyment of direct observations. Ecological arguments about the importance of a species, such as its role in ecosystems or its threats, rank third.

These results may directly impact on conservation policies in the New Caledonian lagoon, which must take into account the social values attached to emblematic species. Policies based solely on ecological criteria are at risk of not meeting people's expectations and therefore not effectively protecting the reefs.

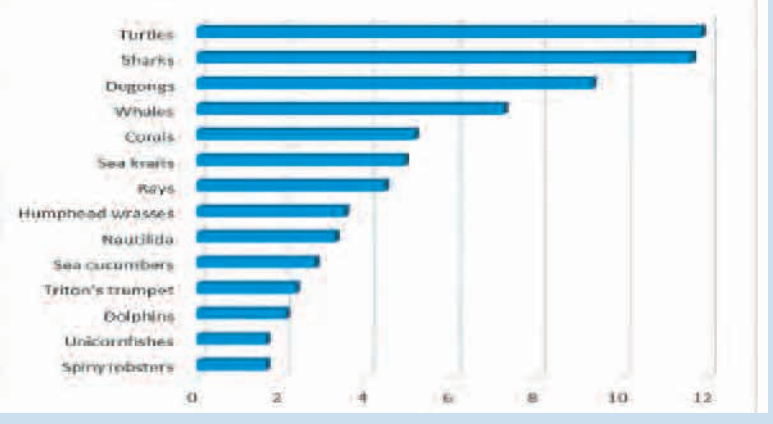



Figure 1: Animals cited by at least 2% of people (number of mentions). It is worth noting the importance of corals, which are selected for their reef-building role. Interviews conducted in 2017 by the authors

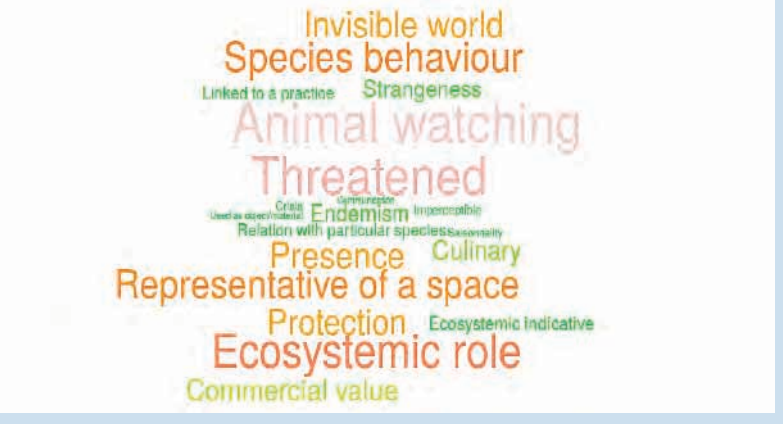
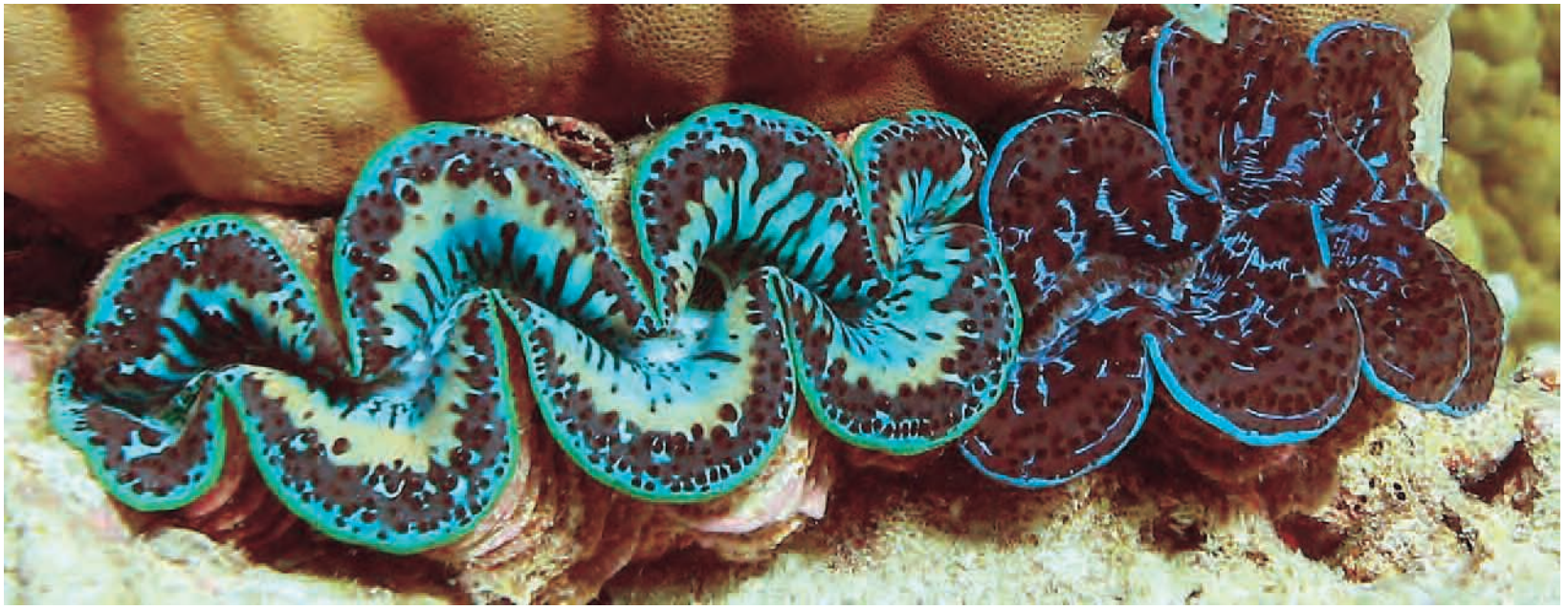



Figure 2: Main reasons given to justify the designation of "emblematic species" (size of words relates to the number of mentions). Interviews conducted in 2017 by the authors

*Chapter 35*

# Giant clams: a resource to preserve

*Cécile Fauvelot, Pascal Dumas and Josina Tiavouane*



*Tridacna maxima* is the smallest species of giant clam and the most sough-after in aquariophilia because of the bright colours of its mantle. © IRD/S. Andréfouët

In New Caledonia, as in many Pacific countries, giant clams are a highly sought-after resource. Their exploitation can threaten their availability and even lead to their disappearance. For instance, *Tridacna gigas*, the largest species, once present on the reefs of New Caledonia, is now only found in fossil form. According to the official statistics of the New Caledonian Fisheries Observatory, the official annual catch figures, recorded between 2000 and 2014, are significant and reach up to 9 tons/year for all species. Since 2009, protective measures have been implemented to stop the observed decline in stocks. For example, the fishing of giant clams is regulated in both the northern (article 341-54 of the Environmental Code) and southern (Article 37 of the Environmental Code) provinces: catches are limited to two giant clams per boat and per day for nonprofessional fishing (recreational and subsistence) and five giant clams per boat and per day for professional fishing.

In the Province of the Loyalty Islands, Kanak customary law alone regulates giant clam fishing, no other legislation applies. The absence of statistical data at the species level, however, is currently preventing the accurate assessment of catch rates per species. This is even more true in the case of undeclared subsistence fisheries, where impacts on the resource are not quantified at all. Despite a positive effect (a decrease in catches) since the introduction of these regulations, available data suggest that the densities of giant clams continue to decrease due to increases in fishing pressure linked to the demographic development of the territory.

*Tridacna gigas* is present throughout the coral triangle as far as the Solomon Islands, but has disappeared from the reefs and lagoons of New Caledonia where fossil shell valves are much sought-after by lapidaries. © IRD/S. Andréfouët

Confronted with the alarming state of the resource and the desire of local communities to keep on consuming giant clams, managers, scientists and local stakeholders must, more than ever, join forces to find innovative solutions. In September 2009, WWF and the Fisheries and Aquaculture Department of the North Province coordinated a restocking operation of the Horse's hoof giant clam, *Hippopus hippopus*, in the two co-managed Marine Protected Areas (MPAs) of Pouébo and Hienghène. In 2012, a genetic study carried out in the Hyabé/LéJao (Pouebo) MPA evaluated the effectiveness of this restocking process and estimated the dispersion range of larvae around the MPA. Coordinated by the IRD, this work revealed that 22% of the giant clams sampled inside the MPA originated from the reproduction of MPA individuals, revealing a high rate of self-recruitment. The study also showed that about a quarter of these "self-recruits" were born from at least one parent issued from the restocking operation, thus proving the effectiveness of this action.

For larval export, the results show that 18% of juveniles sampled on fringing reefs on each side of the MPA are the result of the reproduction of adults located in the MPA, up to about 35 km apart. Re-seeded specimens also participated in exports, with a share of around 30%. Therefore, Horse's hoof giant clam larvae from protected areas, where fishing is regulated, are exported and contribute to the resilience of populations in unprotected areas, emphasizing the importance of these marine protected areas.

**References**

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TIAVOUANE J., 2016 *Les bénitiers de Nouvelle-Calédonie : nouvelles espèces et échelles spatiales de connectivité chez* Tridacna maxima *et* Hippopus hippopus. Marine Biology PhD Thesis, Paris VI University, 191 p.

*Chapter 36*

# Rare and endemic fishes, little-known players that must be preserved

*Michel Kulbicki, Philippe Borsa, Gérard Mou-Tham, LaurentVigliola and LaurentWantiez*

This angelfish *(Pygoplites diacanthus)* is rare in New Caledonia except in the lagoon of Ouvéa. Its rarity may be explained by its diet, largely made of sponges, which are toxic to most other fish. © S. Floeter

Endemic and rare species are often a source of curiosity for both neophytes and specialists (scientists or environmental managers). Is this the case for our reef fish species?

First, how do we define endemism and rarity? Endemism refers to species which occur in only one locality. Depending on the definition of locality, there may be many different scales of endemism. In this chapter, we will talk about local endemism, for species with a geographical distribution restricted to an area of about 500 km in radius, and regional endemism, for species with a distribution range of 1,500 km in radius. These scales may seem relatively large compared to terrestrial endemism, which often has very small distribution ranges. This difference in scale is due to the dispersal capacities of reef fish species, which, during their larval stage, can drift with ocean currents over hundreds of kilometers. There are also several ways to be rare:

– rarity of abundance, for which there are very few individuals of the species throughout its entire distribution range;

– rarity of frequency, where the species rarely occurs, but can be locally abundant.

This means that there is a link between rarity and endemism, since one of the definitions of rarity relates to geographical frequency and, consequently, to distribution range.

## On the importance of these species

For species to be endemic or rare, it is likely that they have unique biological, genetic or ecological characteristics, which makes them particularly important to diversity. For instance, an endemic species can be expected to be better adapted to local conditions than non-endemic species. Similarly, a species may be rare because its biological or ecological characteristics prevent it from being abundant - for example, large species - and this local rarity is often balanced by a large geographical distribution. In any case, rare species are a source of diversity and as demonstrated in the chapter on the ecological functions of fish, available resources are more efficiently used when diversity increases. This results in more stability and resilience to environmental change, but also more ecosystem services, including the production of higher biomass.

## Rare species are difficult to study

A rare species is, by definition, difficult to find and therefore difficult to study. However, sometimes, there is "false rarity" associated with sampling. For example, some species may appear to be rare because of their behavior, such as moray eels which are relatively abundant but live hidden in reef crevices all their life.

Harlequin tuskfish *(Choerodon fasciatus)* are widely distributed in the Pacific Ocean but are rare everywhere. © R. F. Myers

In addition, it is necessary to define thresholds of abundance from which a species is considered rare. In this chapter, we choose a threshold of 10,000 individuals.

Two challenges must be overcome for studying endemic species:
– the definition of the relevant scale, mentioned above;
– the level of knowledge and exploration of fish communities.

An island species can be considered endemic for a long time for the simple reason that the surrounding archipelagos have not yet been properly explored. In the Hawaii Islands, for example, the proportion of endemic species was estimated at about 30% in the 1960s. It decreased to 23% in the 1990s and reached 17% with increasing knowledge of the rest of the Pacific. Conversely, what was once thought to be a single widespread species may turn out to be part of a complex of species. The blue-spotted maskray is a good example: it used to be considered as a single species, but genetics and geographic distributions revealed 11 reproductively isolated, distinct species. Consequently, the rarity or endemism status of a reef fish may be unstable, more than what is observed in the terrestrial environment. This has implications for management policies where a biotope or ecosystem approach will be more appropriate than a species-by-species approach.

## Endemic reef fishes, how many and who are they?

The number of reef fish species endemic to New Caledonia is highly debated. If we focus only on properly identified species, there are currently 27 known local or regional endemic species, representing 1.8% of reef fishes.

Endemic New Caledonian species are mostly bottom dwelling, solitary and active only during the day. They mainly belong to syngnathids, a group that includes seahorses (six species), gobies (five species), blennies (four species) and Tripterygiidae, or triplefins (four species). The three latter families are poorly known and it is likely that the status of several species currently recognized as endemic will change in the near future as new knowledge is acquired.

For example a species recently described from New Caledonia and believed to be endemic, the oblong large-eye seabream *Gymnocranius oblongus*, has since been observed in Taiwan. In contrast, one species of the blue-spotted maskray complex (*Neotrygon trigonoides*) may be unique to the Coral Sea region. To our knowledge, none of the species endemic to New Caledonia is abundant.

The next question addresses what can determine the number of endemic species. Specifically, do the number or proportion of endemic species vary from one region to another in the Pacific? And what are the possible factors that cause variation in reef fish endemism? The distribution of Pacific reef fish endemism is very heterogeneous. Regions with high endemism (between 3.8% and 28%) are all located at the periphery of the tropical Pacific. In contrast, the proportion of endemic species in the central tropical Pacific is much lower, with an average of 1.6% of known species. Regions with high endemism, with the exception of Japan, are all characterized by low species richness. In New Caledonia, more than half of the endemic species are considered "local endemic". This dominance of local endemism over regional endemism is observed throughout the periphery of the tropical Pacific, with the exception of Hawaii and Japan. In this respect, New Caledonia differs from its neighboring regions, such as the Great Barrier Reef, the Coral Sea, Vanuatu or the Solomon Islands, where regional endemism prevails.

In reef fish, the underlying causes of the level of endemism are not well known, but the proportion of endemic species increases in isolated archipelagos, especially if islands are small. Two major groups of endemism can be distinguished: sympatric and allopatric endemism. In the first group, species "split" into two or more species as a result of local isolation, a phenomenon that is often difficult to demonstrate (environmental changes, acquisition of behavior in a group of individuals, etc.). In the second group, populations are isolated from each other and evolve separately until they accumulate sufficient genetic differences to become distinct species. The analysis of the distribution of endemic species throughout the Indo-Pacific suggests that the most common group is allopatric endemism. With the succession of glaciations and subsequent warming, followed by retraction and expansion of coral reef regions, it is likely that many populations have been isolated. Depending on their capacity to recolonize from refuge areas, these populations may or may not have produced new, often endemic, species.

## How many rare species?

The number of rare species depends on the definition of the level of rarity. Figure 1 shows that the proportion of rare species is very high in New Caledonia: 47% of species for a threshold of one individual per 10,000 and 18% for a threshold of 1/100,000. This ratio changes slightly depending on the environment, with poorly diversified reefs having a smaller proportion of rare species. The proportion of rare species increases with island size: for example, it is higher on Grande Terre than on the Loyalty Islands. This proportion also increases with the number of species in the region: the proportion of rare species in Polynesia is only 14% but in Fiji it reaches 29% (at a rarity threshold of 1/10,000).

New caledonian maskray (*Neotrygon trigonoides*). © J.-L Menou

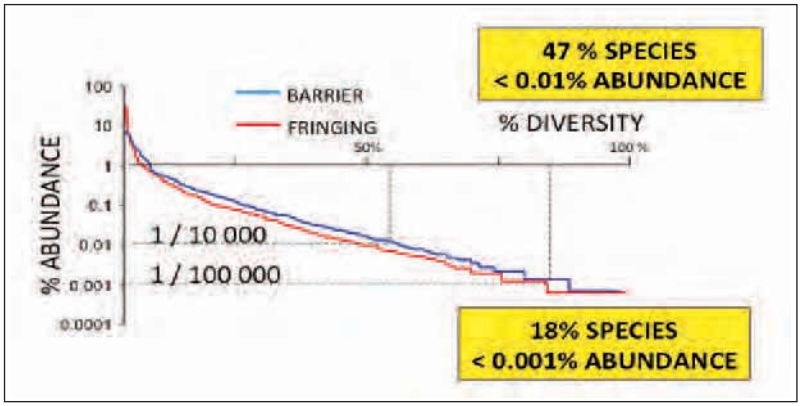


Figure 1: Proportion of rare species on fringing and barrier reefs in New Caledonia. Adapted from JONES, *et al.*, 2002 and MOUILLOT *et al.*, 2013

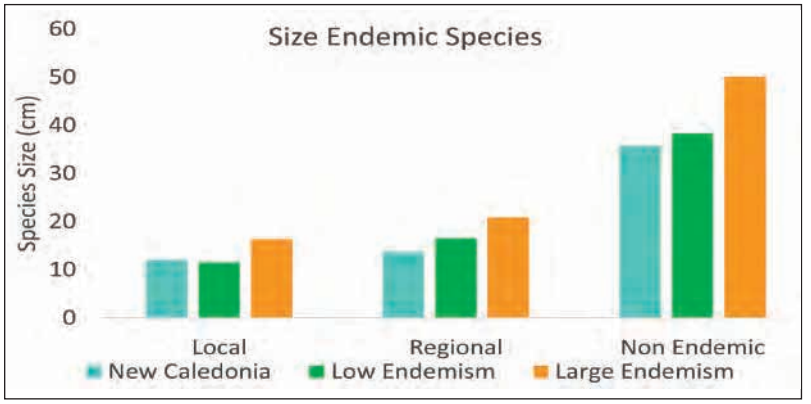


Figure 2: Average size of reef fish species according to their level of endemism (local, regional, non-endemic) and the proportion of endemic species. Regions of low endemism in New Caledonia: < 3.8%; regions of high endemism: > 3.8%.
Adapted from JONES, *et al.*, 2002 and MOUILLOT *et al.*, 2013

## Characteristics of endemic and rare species

Endemic species are, on average, three times smaller (Fig. 2) than other species, with local endemic species being slightly smaller than regional endemics. Similarly, regions with high endemism have larger endemic species than regions with low endemism. These size differences are correlated to the remoteness and size of islands: the smaller an island is and the farther away from the central Indo-Pacific region, the more reef fishes are represented by large species. For example, in Hawaii, the numerous endemic species are represented by a large proportion (30%) of species over 30 cm long, whereas in New Caledonia only 8% of species are over this size.

Endemic species have diets that differ from the average (Fig. 3). They are less often piscivorous, herbivorous or sessile invertebrate (mainly corals) feeders than other species. New Caledonia is distinguished by the absence of these three types of diet among its endemic species. In contrast, endemic species in New Caledonia are more frequently omnivorous than in other regions.

Rare species are mostly carnivorous (50% of carnivorous species are rare) or piscivorous (20%) and are mostly (55%) of medium size (8-30 cm). More importantly, the ecological function of rare species is often unique. In other words, each rare species tends to have a very specific ecological function. Its disappearance would therefore lead to the disappearance of its function.

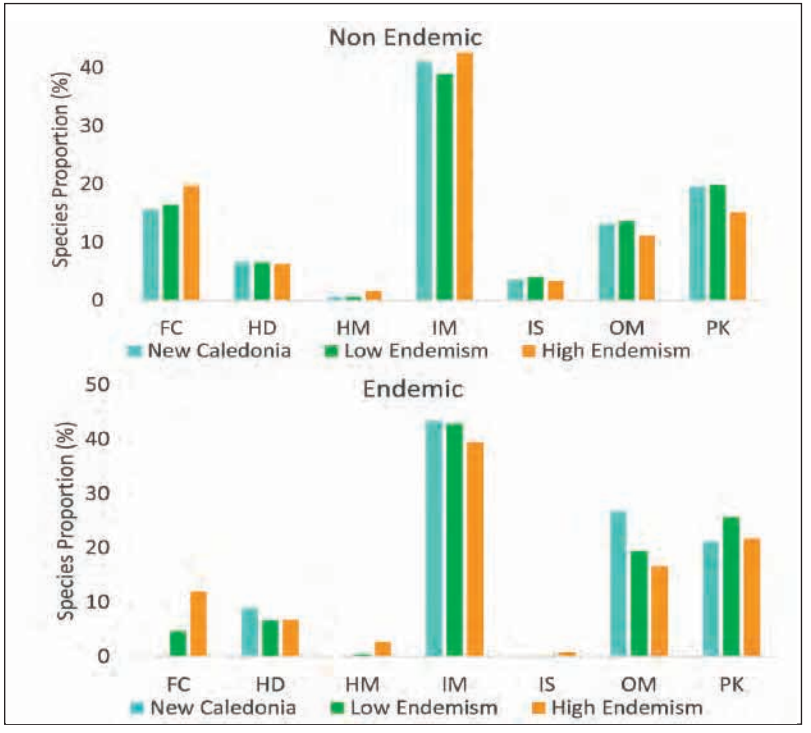


Figure 3: Diet of reef fish species according to their endemism and the level of regional endemism.
FC: Piscivorous; HD: Turf herbivorous; HM: Macroalgae herbivorous; IM: Mobile invertebrate feeders; IS: Sessile invertebrate feeders (corals); OM: Omnivorous; PK: plankton feeders.
Adapted from JONES, *et al.*, 2002 and MOUILLOT *et al.*, 2013

Mandarinfish *(Synchiropus splendidus)* are rare and difficult to observe, they often hide among *Diadema* sea urchins in coastal areas. © R.F. Myer

## On the role of endemic and rare species

The role of rare species is still very poorly understood, but their rare ecological functions suggest that, although they are not essential, they contribute significantly to the diversity and thus to the stability and resilience of reef communities. The role of endemic reef fish species in New Caledonia is probably negligible for the functioning of the reef communities because they are never abundant. The situation is different in regions with a high diversity of endemic species (>8%), particularly in the Hawaii Islands and Easter Island, where these fish species represent 30% to 60% of the abundance depending on the island.

## Management and conservation

Rare and endemic species are frequently the focus of conservation programs in terrestrial environments because they are often threatened. The same applies to certain marine species, such as the endemic shellfish, dugongs or lobsters off Bourail. The reef fishes that are currently threatened in New Caledonia are all emblematic species (chap. 38), which is not, or almost not, the case for rare or endemic reef fishes. So how and why should we protect them?

How? In New Caledonia, rare or endemic species occupy very diverse habitats. It is therefore difficult to manage these species specifically. For this reason, it is necessary to implement a comprehensive management policy that focuses more on protecting habitats and preserving environmental conditions than on protecting particular species. This is very different from the terrestrial environment, where it is possible to protect targeted species such as kagu, parakeets, crow honeyeater or endemic plants, although habitat conservation, such as dry forest, also protects a range of species, including endemic or rare species.

Why? These species often provide specific ecological functions which lead to an increase in ecosystem services that is often much more important than would be expected given their rarity. Many of these species are particularly beautiful, the angelfish being perhaps the archetype of such a species. A decline in diversity, which most commonly involves these species (Fig. 1), is often a strong signal of disturbance. The analysis of the diversity-abundance curves can provide a prompt detection of the early stages of degradation.

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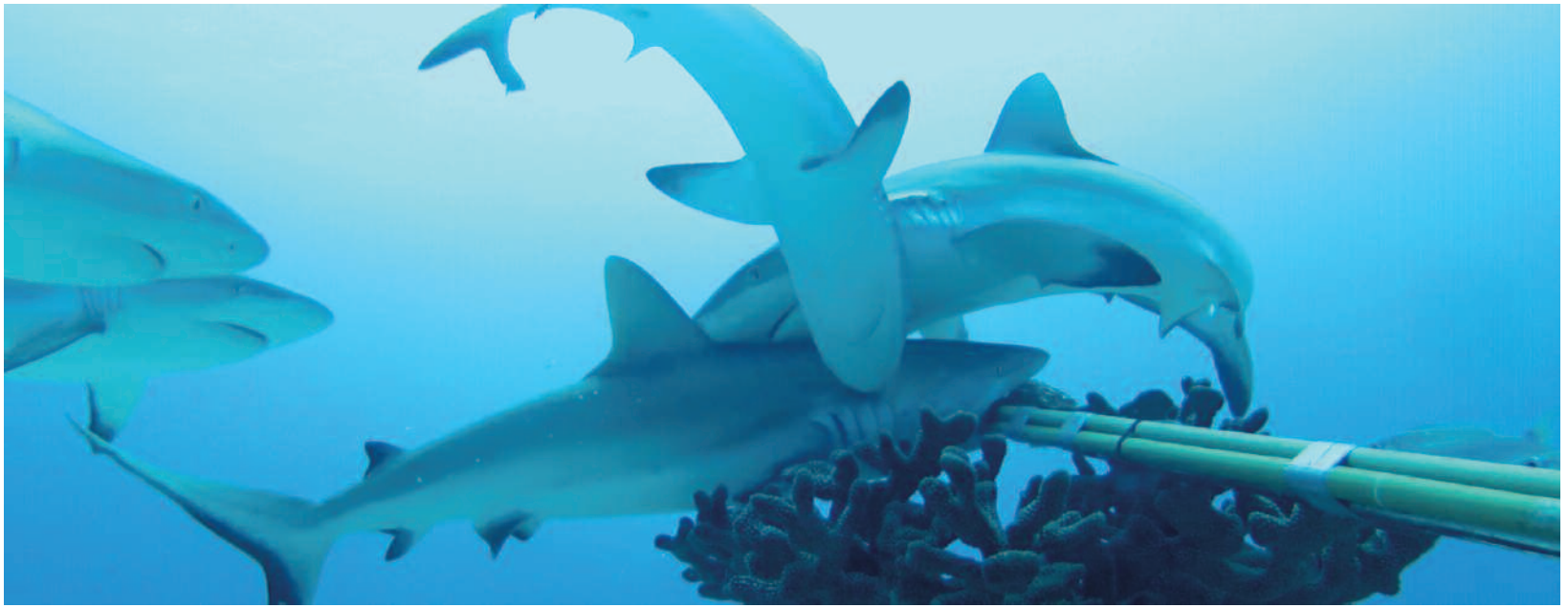
*Chapter 37*

# Where are the sharks?

*Laurent Vigliola, Jean-Baptiste Juhel, Laurent Wantiez and Michel Kulbicki*



Grey reef sharks recorded by a baited stereo camera at Astrolabe Reef. © IRD/L. Vigliola

Although they are among the most powerful predators of the oceans, sharks are highly vulnerable and many species face a significant risk of extinction throughout the world's oceans. Recent studies show that 97 million sharks are killed each year by fishing and that some populations have declined by 99% (WORM *et al.*, 2013). Unlike other fish that lay millions of eggs every year, sharks can only give birth to a few pups in their lifetime. For example, the grey reef shark, *Carcharhinus amblyrhynchos*, reaches sexual maturity at 10 years of age, at which point females can start giving birth to one to five pups every two years. The gestation period is one year. With such a slow reproductive rate, it will take decades for decimated shark populations to recover.

With a relatively small human population compared to the size of the lagoon, and with no history of industrial shark fishing and a recent formal ban, New Caledonia sharks should have been relatively spared. However, that is not the case. As part of the PRISTINE[25] and APEX[26] projects, we deployed 385 baited camera units and carried out 2,790 underwater dives to sample reef shark communities throughout the New Caledonia Archipelago.

[25] http://pristine.ird.nc
[26] http://apex.ird.nc

*Carcharhinus amblyrhynchos* (grey reef shark); the behavior of the two animals suggests a mating episode. © M. Juncker

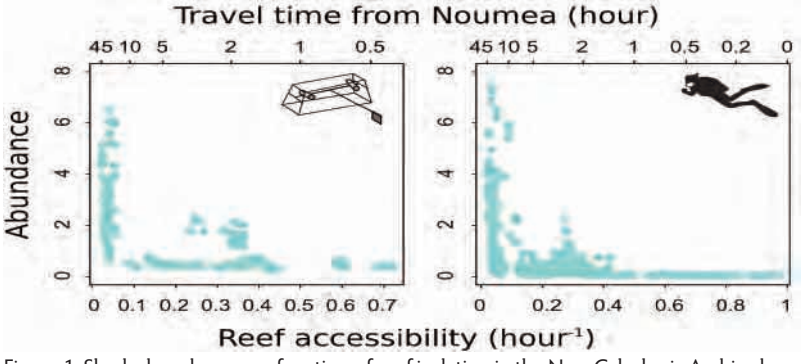



Figure 1: Shark abundance as a function of reef isolation in the New Caledonia Archipelago using baited stereo-camera (left) and visual census by scuba divers (right). Adapted from JUHEL *et al.*, 2018

Our results show that reef sharks are more diverse and abundant in the isolated reefs of the archipelago. There, more than 25 hours away from the capital Nouméa, they are sheltered from most human impacts. However, these emblematic animals have virtually disappeared from reefs close to human populations (JUHEL *et al.*, 2017). The impact is very severe, with a decline of 97% in shark abundance and 94% in species richness in reefs within an hour of Nouméa compared to isolated reefs (Fig. 1).

Many hypotheses could explain this disappearance, the exact causes of which are not identified. For example, the residual effects of historic, illegal or accidental fishing, overfishing of prey, habitat degradation, pollution, or disturbance during reproduction. Whatever the causes, the disappearance of sharks is worrying because, as large predators, sharks have a major structuring role in natural ecosystems (RUPPERT *et al.*, 2017). However, solutions to these problems do exist. Large marine nature reserves (over 200 km$^2$), where human presence is strictly prohibited, have positive effects on shark abundance and diversity. The creation of this type of reserve (strict nature reserve) requires large areas and some degree of isolation. These conditions are found in the vast southern and northern lagoons in particular, but also in the immense Natural Park of the Coral Sea, where sharks can find an ultimate refuge. With the use of these parks and reserves, New Caledonians still have the opportunity to effectively and sustainably protect sharks occurring on their reefs.

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*Chapter 38*

# Emblematic fish species as flagships of participative ecology?

*Michel Kulbicki, Philippe Borsa, Gérard Mou-Tham, Laurent Vigliola and Laurent Wantiez*

Reef manta rays *(Manta alfredi)* attract the public's attention because of their size (several meters wide), strange morphology and spectacular behavior. They are the most symbolic of species that promote environmental preservation. © IRD/G.Boussarie

Scientific research is receiving more and more media coverage. This provides ways of communicating the latest knowledge to decision-makers and the public, who can then develop an informed opinion. To reach as many people as possible, the information must be accessible and allow non-experts to understand complex systems such as coral reefs. Emblematic species enable this bridge between science, population and decision making.

To qualify as emblematic, a species has to meet one or more of the following conditions: perform an essential ecological function, be affected by disturbances, have a broad geographical distribution and have the potential to arouse media attention.

In reef fish, three main groups of species can be classified as emblematic. First, very large species such as sharks (chap. 37), large rays, giant groupers, Napoleon wrass or humphead parrotfish. These easy to identify species are all highly sensitive to disturbance, especially fishing, and many of them perform key ecological functions. The second group is made up of small, colorful, and easy to identify species, which are also sensitive to changes in the environment.

Examples include butterflyfish, angelfish and clownfish. The last group also includes species of great local cultural importance, such as short-nose unicornfish *(Naso unicornis)*, emperor red snapper *(Lutjanus sebae)*, emperors *(Lethrinus* spp.*)*, *mïkwaa or* milkfish *(Chanos chanos)* or rabbitfish *(Siganus lineatus)*. These different groups play different roles in our approach to environmental conservation.

The first group is the most mediatized. The spectacular nature of these species makes it is possible to raise public awareness about the ecological and societal challenges related to the maintenance of these species, which contributes to the preservation of their environment. In New Caledonia, it was possible to take measures to preserve the Napoleon wrass *(Cheilinus undulatus)* following an international awareness-raising campaign on this species, whose numbers are threatened in the most populated areas. Another species, which is more economically significant, the humphead parrotfish *(Bolbometopon muricatum)*, is still fished despite its acknowledged key role in the functioning of reefs.

The development of ecotourism has also made possible the in situ observation of species such as sharks, manta rays and giant groupers not far from the most populated zones of the territory. If these species were to experience a decline in numbers, it is likely that populations would be alerted and new protection or management actions would result. However, many of these fish species are concentrated in protected areas and their overall abundance may decrease without significant changes in the protected populations.

The second group is more accessible. It includes, for example, the butterflyfish which can be observed on all the reefs of the country. These fish are very sensitive to changes in their habitat. Butterflyfish are also very strongly linked to corals and this means that they can be used to detect changes in the quality of coral cover over the medium and long term, and they are often proposed as indicators of environmental conditions.

In addition, because of their diversity (34 species in New Caledonia) and because they can be identified easily, they are included in most participative science programs such as the Global Coral Reef Monitoring Network (GCRMN) and the RORC (New Caledonia Coral Reef Observation Network). Participative science has largely demonstrated its potential in terrestrial environments, but the complexity of reef ecosystems makes its application here more difficult.

The last group is relatively difficult to define because its composition is more variable. Most are species of longstanding economic or societal importance. In general, these species are medium to large in size and are an important part of the fish biomass. Before the arrival of Europeans, the capture, keeping or use of these species was often governed by complex rules. Examples include the short-nose unicornfish *(Naso unicornis)* on the island of Tiga, whose fishing was controlled by a set of customary rules, and the *mïkwaa* or milkfish *(Chanos chanos)* which is still ruled by community fisheries in several tribes. Species in this group are not listed anywhere but they are part of the local culture. Local populations would not remain unaffected by a significant decline in the number or size of species such as rabbitfish, large-eye seabream, lyretail grouper or mullet. Although there are ecological indicators based on the density and biomass of some of these species, these are not yet widely used in management strategies. However, the public's reaction to significant changes can lead to decision being made. For instance, the rarefaction of giant groupers *(Epinephelus coioides* and *E. malabaricus)*, followed by their sudden abundance after the discovery of their spawning grounds, generated reactions that led to regulations. Furthermore, the rarefaction of rabbitfish has also led to aquaculture trials.

To date, emblematic reef fish species have no specific status in New Caledonia, but consultations are ongoing. This is an opportunity to better define these species and introduce measures to protect them, to use them as indicators or specifically to preserve their population levels and quality. Most of these species are part of the country's cultural heritage, as are kagus, parakeets, Norfolk pines, kaoris or freshwater prawns. Beyond their preservation, they are an important means of communication and exchange between the public and decision-makers.

*Chapter 39*

# The marine turtles of New Caledonia

*Tyffen Read and Richard Farman*

The hawksbill sea turtle *(Eretmochelys imbricata)* is in critical danger of extinction. This species is hunted for the quality of the shell scales. © G. Boussarie

Five of the eight marine turtle species recorded worldwide are found in New Caledonia. However, their numbers vary considerably. Leatherback sea turtles (*Dermochelys coriacea*) only transit through exclusive economic zones and observations of the olive ridley sea turtle (*Lepidochelys olivacea*) are anecdotal, and probably due to animals that travel off-track. However, the other three species, the green sea turtle (*Chelonia mydas*), the loggerhead sea turtle (*Caretta caretta*) and the hawksbill sea turtle (*Eretmochelys imbricata*) are frequently observed in the lagoon. Worldwide, the IUCN (International Union for Conservation of Nature) classifies green and hawksbill turtles as endangered, and loggerhead turtles as vulnerable.

## Two major rookeries

New Caledonia hosts two of the major rookeries for green and loggerhead turtles in the Southwest Pacific. In terms of importance, these sites are second only to Australia, and the loggerhead breeding site is the only other rookery for this species in the rest of the Pacific islands.

The green turtles of New Caledonia come from several genetic groups, mainly those of the d'Entrecasteaux Reefs (independent), and the Coral Sea, including turtles that lay their eggs on the Chesterfield Atolls, and those of the northern and southern Great

Barrier Reef. However, there is very little connection between these different groups. Females are very faithful to their breeding sites during the same season (a female lays eggs several times during a season), but also between successive seasons. The inter-season gap is estimated at an average of 8.35 ± 3.30 years.

While feeding sites for green turtles can be found throughout the lagoon, particularly on the west coast, rookeries are mainly located in the north of Grande Terre and in the Loyalty Islands. The main exchanges have been documented between feeding sites and rookeries in Australia and New Caledonia, suggesting the existence of migration corridors not only between the two countries, but also within each country.

In fact, 61% of the green turtles in the Southern Lagoon (Grand Lagoon Sud) come from the d'Entrecasteaux Reefs rookery, 24% from Australia and less than 5% from the Chesterfield/Coral Sea area. The number of green turtles feeding in New Caledonia is unknown. It is estimated that there are several thousand females at the rookery of d'Entrecasteaux Reefs, a few hundred more in the rest of the lagoon and a similar number at the Chesterfield site. The size of the Southern Lagoon's population fluctuates considerably with a high prevalence of juveniles (88%) and an absence of adults, which is a concern. This imbalance is due to the high recruitment of new animals, which are easily identified by the color of their plastron.

## Turtle population displacements and anthropogenic impact

In this area, it has been estimated that the vital range of a turtle is on average 54 km$^2$ with, however, a high variability from one area to another and no exchange between areas.

Professional longline fishing has little impact on the populations of green turtles (one catch between 2006 and 2008 and three in 2016). However, fisheries that are authorized by derogation for customary ceremonies have been estimated at about 500 individuals in 2014. A number of animals are also illegally caught, but there is no available estimate of the scale of this.

Loggerhead sea turtle equipped with a transmitter beacon to study the migration of the species between egg-laying and feeding sites. © Aquarium des Lagons

Egg lating of *Chelonia mydas*. © G. Boussarie

At the end of long apneas, the turtles go up to breathe on the surface. *Chelonia mydas*. © G. Boussarie

Loggerhead turtles belong to the Southwest Pacific genetic group. There is very little exchange between the different genetic groups of this species (only five at the global level), which is a major management constraint as conservation efforts have to be applied to all age groups, especially younger individuals, including those caught in the bycatch of South American fisheries. Here again, the exchanges between New Caledonia and Australia have been documented. Females marked at the site of the Roche Percée were tracked all the way to Australia (Moreton Bay, Cape York and the Gulf of Carpentaria) or Papua New Guinea (Trobriand Islands).

As for juveniles, their movements are closely associated with the 19°C isotherm, which they follow to New Zealand where they stay for some time, then cross the Pacific Ocean to the South American coasts before returning to recruit in the region's coastal habitats.

Just as for green turtles, we do not know the number of loggerhead turtles feeding in the New Caledonian Lagoon, although it is estimated that there are about 50 females that visit the main rookery of the Roche Percée in Bourail. It is believed that they are at least as equally distributed on the islets of the Southern Lagoon and there are also some who feed in the north.

Females demonstrate a very high-fidelity rate to their breeding sites during the same season, but also between successive breeding seasons. The interval between seasons is 2.84 ± 1.27 years and the interval between egg laying during the same season is 15.14 ± 1.44 days.

Loggerhead turtles are not fished but egg poaching has been reported at the Roche Percée site (13% of nests were looted). Furthermore, though there was no bycatch by the New Caledonia longline fleet between 2006 and 2008, up to 3,000 individuals are caught annually by Peruvian fisheries, of which 92% are reported to be released alive.

To date, egg laying by hawksbill turtles has never been observed in New Caledonia. It is the least known and probably the least abundant species, even if it is often found in the lagoon (its feeding ground). In addition, an unknown genetic group has been identified at several sites in the region, which could be explained by the existence of another rookery in New Caledonia.

Loggerhead sea turtle *(Caretta caretta)* swiming along the external reef slope. © J.-L. Menou

All marine turtle species are fully protected internationally by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and locally by the environmental codes of the North and South Provinces and by the regulations of the Loyalty Islands Province and New Caledonia. In addition, any catching, disturbance, keeping or destruction of any species is prohibited, as is the destruction of nests, the sale of eggs and marketing of any kind whatsoever.

Given the conservation status of these species (vulnerable or endangered), their heritage value, particularly for local populations, and the importance of New Caledonia for conservation at a regional level, a local action plan is being prepared. The aim is to establish priorities and allocate tasks, to combat, in particular, the effects of climate change that will impact rookeries (coastal erosion, rises in nest temperature, changes in the sex ratio, etc.). In this instance we must, just like the turtle, learn how to get off to a good start. Perseverance leads to success even without the best assets.

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*Chapter 40*

# Seabirds as sentinels of New Caledonian waters

*Éric Vidal, Karen Bourgeois and Philippe Borsa*

Juvenile masked booby *(Sula dactylatra)* © M. Junker

With several hundred islets scattered like confetti over a vast oceanic and lagoon area, the coral reefs of New Caledonia provide exceptional nesting sites for a diverse and abundant seabird community (chap. 20). Seabirds are one of the world's most threatened animal groups and their risk of extinction is increasing faster than any other bird group. Seabirds are valuable bio-indicators of the direct and indirect impacts associated with human activities, both on land and at sea. This is because most of these species are long-lived and share their existence between their terrestrial breeding colonies (particularly on coral cays) and the sea (for foraging and during inter-nuptial periods). They are major predators positioned at the top of the marine food chain. In addition, because of their sensitivity to environmental changes and disturbances, which affect feeding and breeding sites, environmental managers consider them as "sentinel species", capable of informing on the condition of natural marine and island areas.

They also represent interesting "umbrella species": while the conditions for their sustainable conservation can be met (e.g., MPAs), their high ecological requirements, particularly in terms of habitat quality and surface area, mean that they can, in turn, benefit a wide range of other species, communities and ecosystems. In New Caledonia, the importance and diversity of coastal and island environments, and the quality and size of lagoon and ocean ecosystems, mean that the seabird community is both numerically

very large and diverse in terms of species, but also faces major conservation challenges due to the presence of threatened species. Nonetheless, the seabirds of New Caledonia's coral cays face a variety of threats associated directly or indirectly with human activities.

At nesting sites, seabirds are impacted by introduced animal species, including rodents such as the black rat, Polynesian rat or domestic mouse, which prey on eggs and chicks, or invasive ants such as the electric ant which inflict severe stings. Their breeding habitat is also altered by the introduction of different plant species. The seabird community is highly sensitive to disturbances caused by visitors and to the sometimes devastating consequences of tourist developments. Past operations, such as the industrial exploitation of guano on some islands of the d'Entrecasteaux and Chesterfield reefs have also had a lasting negative impact. More recently, new questions have emerged on the possible effect, in the near future, of rising sea levels and more frequent flooding on the availability and quality of seabird breeding grounds on low coral cays. These issues are complex because coral cays and islets are not "passive" geological features. Their evolution over time depends on complex sedimentary and physical processes.

At sea, the threats may seem more diffuse but they are very real. They include changes in the oceanic environment, such as changes in food availability caused by climate change, pollution and biocontamination that particularly affect the physiology of higher predators (heavy metals, pesticides), or even the ingestion of plastic debris or accidental catches by fishing gear. Seabirds have to deal with a dense array of modern threats, the severity of which is still insufficiently documented in New Caledonia and requires further research.

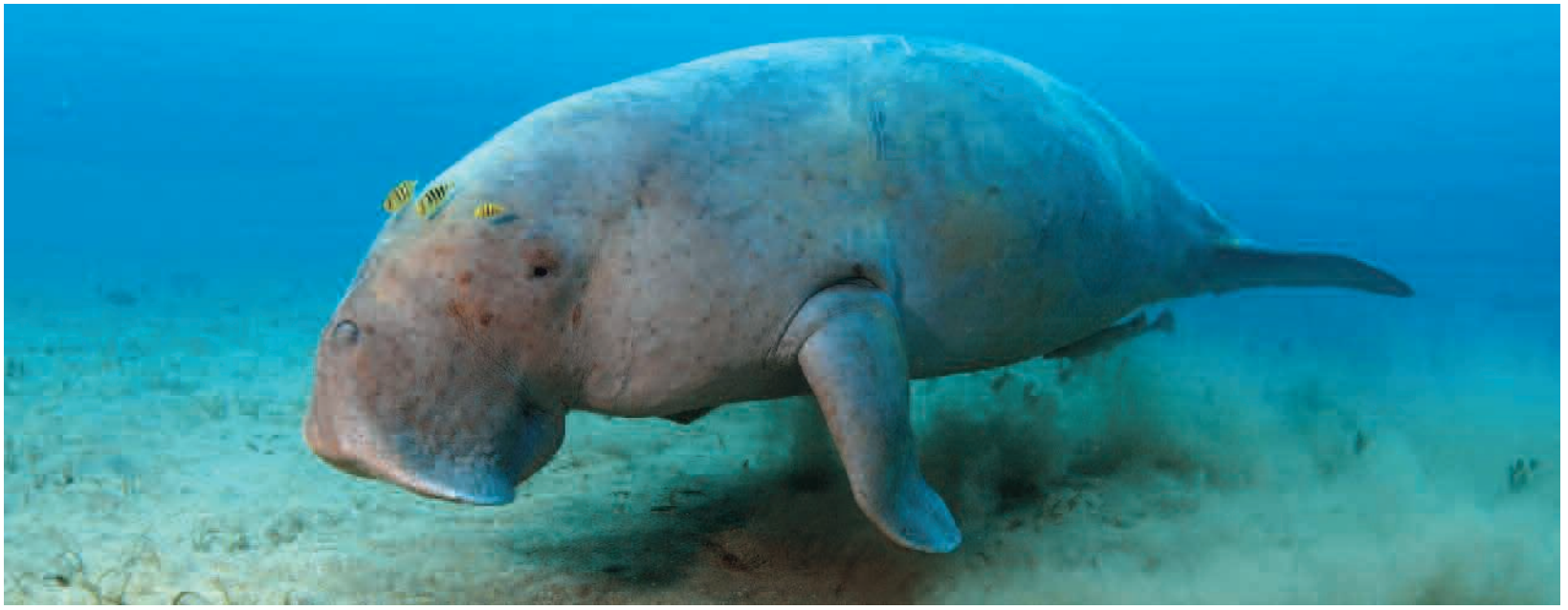
While basic scientific knowledge is being developed for some of New Caledonia's coral reef seabird species, there are still important gaps. Several research programs, recently launched or under development, should be able to fill in these gaps. To name only two: the BIOPELAGOS program, supported by the SPC, IRD and CNRS, is currently aimed at better understanding the use of New Caledonia's oceanic environment by the seabird community. This program combines the monitoring of seabird movements using miniature electronic devices, with the analysis of the characteristics of ocean habitats preferred for foraging and the study of their diet using different methods (regurgitation analysis, determination of nitrogen and carbon stable isotopes, and DNA barcoding of feces). Other scientific programs aim at filling gaps in knowledge about the communities, numbers, reproduction and demographics of seabirds found on some remote islands; to better understand the reproductive biology of different species (many of which have been studied very little); or to clarify the extent of land-based threats such as invasive species or changes in the environment. All these data will contribute to a database implemented by the IRD, which will be made available to environmental managers to improve the sharing of knowledge and data. This should contribute to the sustainable and informed management of the exceptional biological heritage of New Caledonian waters.

Pair of Lesser frigatebird *(Fregata ariel)*. This species is particularly sensitive to human disturbance, which explains why it seeks isolated sites. Mouillage Islets, Chesterfield, April 2017. © IRD/E. Vidal

*Chapter 41*

# Dugongs: endangered lagoon mermaids

*Christophe Cleguer and Claire Garrigue*



A dugong (*Dugong dugon)* swimming above a diffuse seagrass bed in search of food. © M. Juncker

## On the identification of dugongs

With its massive, 3 m long, fusiform and bronze body, its small eyes and broad smile, its lack of dorsal fin, its paddle-shaped pectoral fins and its flattened tail resembling that of cetaceans, dugongs do not go unnoticed in the lagoons of New Caledonia. Also called a "sea cow", the dugong is the only herbivorous mammal that is exclusively marine. From the end of the 18$^{th}$ century, it became the only representative of the Dugongidae family since his cousin the Steller's sea cow was hunted to extinction by humans.

The dugong can be found in shallow coastal areas from East Africa to Vanuatu, through the Middle East and Southeast Asia. In these waters, dugongs find their main larder: the seagrass meadows.

Often found in protected bays, mangrove channels or the leeward coasts of islands, the dugong appears to be a very sedentary animal. However, it makes daily, seasonal, and even random movements of a few dozen to a few hundred kilometers. In New Caledonia, satellite monitoring of a dozen dugongs revealed that they used both the lagoons and the outer zones of the barrier reefs of Grande Terre. Some of them even covered about a hundred kilometers and crossed the administrative borders of New Caledonia's provinces (CLEGUER, 2015).

The dugong reaches its sexual maturity relatively late - between six and 17 years of age. Its gestation and breastfeeding periods are long, between 13 and 15 months and 14 and 18 months, respectively. Its reproductive rate is low (only one young every two to seven years) and is largely influenced by the availability of food resources. As a result of all these characteristics, the dugong is a species that is highly vulnerable to the natural and anthropogenic disturbances of its environment.

Protected by several international laws and listed as a "vulnerable" species on the International Union for Conservation of Nature (IUCN) red list, the dugong has already disappeared from many countries such as Mauritius, the Maldives and Cambodia, and its conservation status remains unknown throughout half of its distribution range. The causes of such vulnerability are multiple and they vary geographically. The most prominent threats include the degradation of seagrass habitats, hunting, accidental capture in fishing nets and collisions with boats. To address these pressures, multiple and diverse conservation and management initiatives are being implemented at the international, regional and local scales.

## Dugongs of the New Caledonian reefs

In New Caledonia, aerial surveys have increased knowledge of the abundance and distribution of dugongs around Grande Terre. Dugongs are mainly distributed on the west and northeast coast of Grande Terre (Fig. 1) and areas of high dugong density are heterogeneously distributed. These hotspots are located in the regions of Nouméa, Ouano, Bourail-Poya, Koumac and Pouebo (Fig. 2). Dugongs are rare in the center of the east coast, as well as in the northern and southern lagoons, probably due to unsuitable habitat.

No aerial surveys have been carried out in the Loyalty Islands, but there are indications that only very few dugongs live there. The most recent observations of dugongs in the Loyalty Islands date back to 2015, when one individual was observed in Lifou and then in Ouvéa, one month apart.

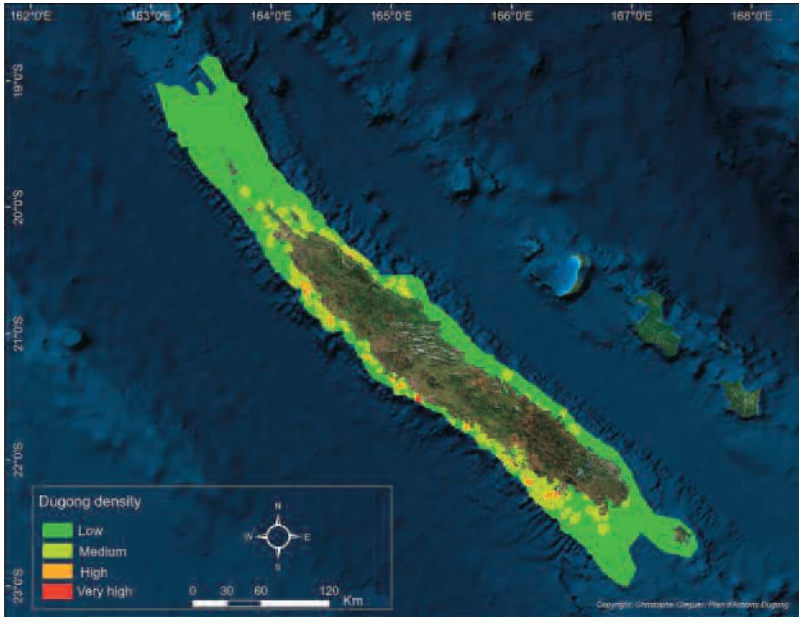



Figure 1: Distribution and density of dugongs around Grande Terre, based on aerial surveys conducted between 2003 and 2012. Adapted from CLEGUER, 2015

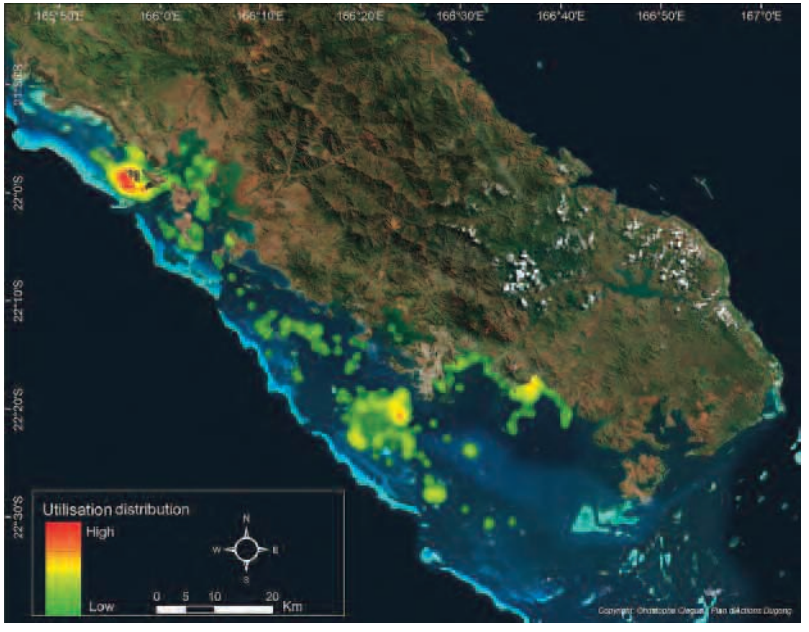
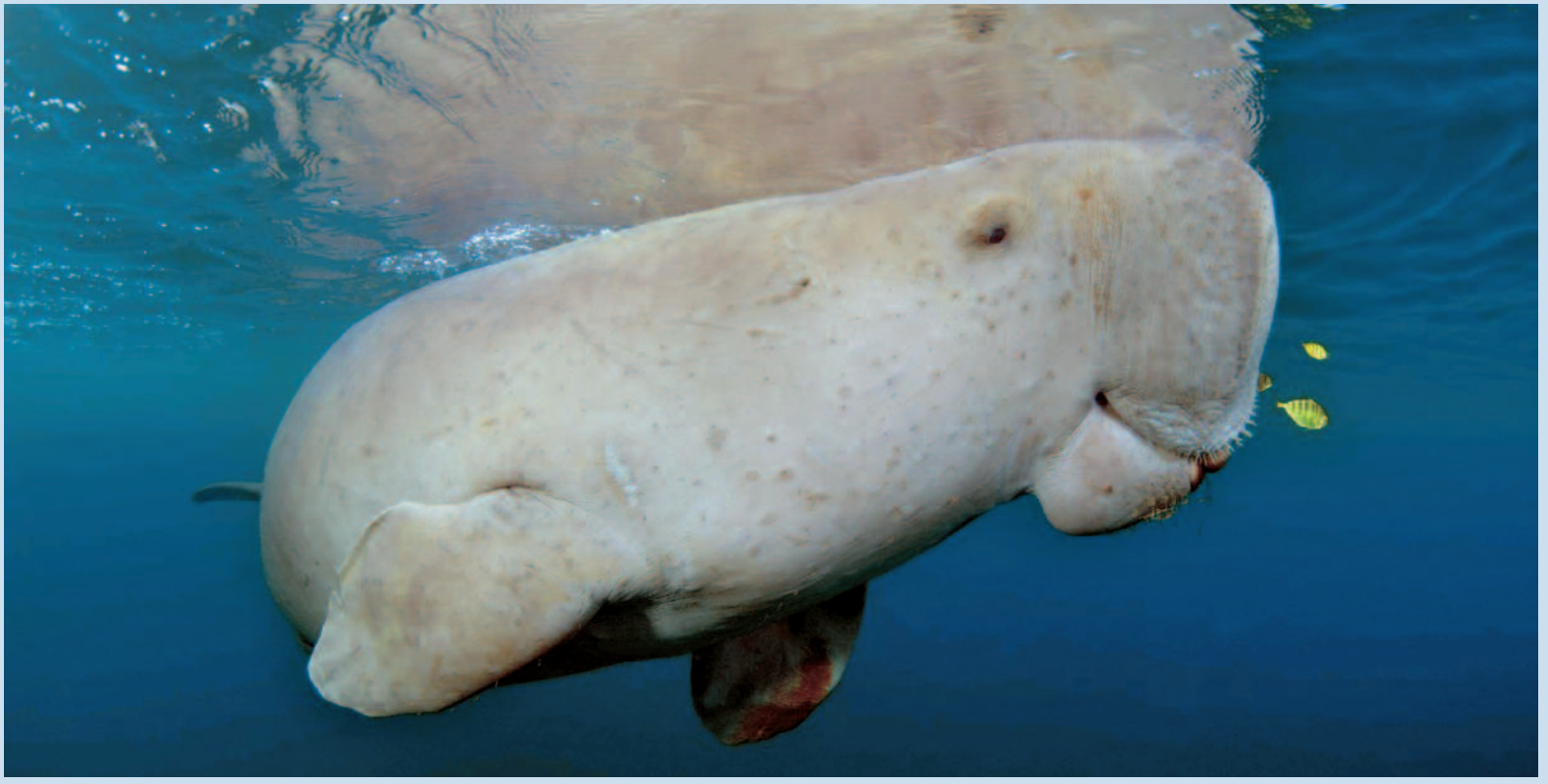



Figure 2: Trajectories of three dugongs equipped with satellite tags in the southwestern region of Grande Terre. Adapted from CLEGUER, 2015. Map © ESRI

*Box 28*

## Dugong: a highly protected species



A dugong in midwater. Several scars from old wounds are visible on the surface of the body and indicate collisions with boats or other watercrafts. © M. Juncker

The dugong is protected by several international laws. The Convention on International Trade in Endangered Species (CITES) of 1973 lists dugongs in its Appendix I, which includes the most threatened species and prohibits "international trade in their specimens". Dugongs are also listed in Annex II of the 1979 Bonn Convention on migratory species of wild animals (CMS), which lists species with "an unfavorable conservation status as well as those that can significantly benefit from international cooperation" (CMS, 2009). A Memorandum of Understanding (MOU) was signed in 2007 on "the conservation and management of dugongs and their habitat throughout their distribution range". The species is also listed as vulnerable to extinction on the red list of the International Union for Conservation of Nature (IUCN).

In New Caledonia, dugong hunting has been banned throughout the territory since 1963. Since 2004, the South Province authorities have completely banned hunting, even for customary events. In the North Province, exemptions may still be granted for specific customary celebrations. However, the number of exemptions granted is low (15 between 1995 and 2004, none since 2004).

The latest population size estimates in 2012 suggest that less than 1,000 individuals are left in the New Caledonian lagoons. This is much lower than the initial estimate of 2,000 dugongs which was made in 2003. Although it is impossible to confirm a decrease in the population, we now know that every individual counts for the survival of the population. This precarious status, confirmed by genetic analyses, results in the fragility and probably low resilience of the dugong population. In other words, each animal removed from the population is a direct threat to the survival of dugongs in New Caledonia.

However, the causes of dugong mortality in New Caledonia are still poorly studied. The recorded strandings and various studies conducted on New Caledonian dugongs over the past decades suggest that poaching, accidental capture in fishing nets and collisions with boats are the main threats.

## Conservation

Aware of the urgent need to preserve dugong populations, a technical group involving the three provincial authorities, the government of New Caledonia, the customary senate, the State, WWF-NC and the association Opération cétacés, launched a five-year dugong action plan (PAD, Plan d'actions dugong) led by the French Agency for Biodiversity (AFB) in 2010. One of the first actions taken by the technical group was to launch research projects in order to improve knowledge of the local dugong population. A PhD project was dedicated to studying the temporal variability of dugong abundance and distribution, and their use of the reefs at different spatial and temporal scales in New Caledonia (CLEGUER, 2015). This study also provided inputs for discussions on the conservation strategies for dugong in the territory. An anthropological study combining traditional knowledge and current practices, and focusing on the importance of dugong in New Caledonian society was then undertaken (DUPONT, 2015). In addition, two studies on the population genetics of dugongs were conducted to assess genetic diversity and explore the connectivity between the dugong populations of New Caledonia and neighboring countries (OREMUS *et al.*, 2015).

Results of these scientific studies confirmed the fragility of the New Caledonian dugong population and highlighted the areas where conservation and management measures must be implemented to improve the protection of the species. Some awareness-raising actions have already been taken, such as informing local sea users of the risk of collisions between dugongs and boats or other watercrafts.

A second ongoing action plan (2015-2020) led by the Conservatory for natural landscapes (CEN, Conservatoire des Espaces Naturels) will help to maintain this momentum and tackle other major issues such as dugong poaching and catches in fishing nets. Other actions will follow, such as monitoring the conservation status of the species in New Caledonia, acquiring new knowledge, and maintaining the preservation of the dugongs by awareness-raising, and informing and engaging New Caledonians.

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*Chapter 42*

# Local knowledge to manage and regulate reefs

*Catherine Sabinot, Estienne Rodary, Marlène Dégremont, Victor David and Gilbert David*


The knowledge of fish passageways is often shared at sea without any cartographic support, but many fishermen know perfectly well how to locate their routes on a map. Vao, Isle of Pines, 2016. © M. Juncker.

New Caledonia is a sparsely populated territory, but its inhabitants are passionate users of the lagoons and reefs. This prompts authorities to implement reef management measures, i.e., to organize and control access and uses. This management is usually carried out by professionals, supported by technical and scientific knowledge which is driven mainly by ecology and biology, and/or following international engagements that involve both ecological and political stakes. In most cases, scientific knowledge is the main driver in creating regulations to maintain reefs and their species in a "good ecological state". However, this management can also be driven by other types of non-scientific knowledge. This local, "vernacular" knowledge, which conveys local values and norms, sometimes called "traditional" knowledge, is owned by different stakeholders and social groups who are users of the reefs. They often are complementary to scientific knowledge and are sometimes linked to sustainable reef management practices. Knowing and taking into account local knowledge can then directly guide reef ecosystem use practices. It can also inform scientific knowledge and involving the various users in the development of common rules promotes efficient management. When these rules become governmental or provincial laws, which are meant to be accepted by everyone, there is more chance that they will be followed by the people of New Caledonia if they are informed by local knowledge. Knowing, informing and recognizing local knowledge is therefore an essential step in the process of building and changing environmental regulations.

The decked pirogue of the Isle of Pines allows to move discretely to catch fish. It still exists today thanks to a few elders who passed on their knowledge to their children, both on how to build the pirogue, and also to locate schools of fish and cast the net. © M. Juncker

## Local ecological knowledge is based on a regular experience of the environment

"When the whales arrive, their breath looks like smoke. It reminds us of how to burn the field for its preparation. They clap with their fins, like when you plant the yam." (Grand Sud). The arrival of the whales informs locals of the time to plant yams.

"When the *iiletch* tree is flowering or when oulek reeds are blossoming, it means that the dawas [*Naso unicornis*] are fat. When the *wiitch* tree makes fruits, it means that the oysters are full." (Hienghène). The blossoming and fruiting of terrestrial plants indicates the favorable season for fishing and the harvesting of certain fish and seafood.

Local ecological knowledge is empirical knowledge, linked to practices and to an "engagement" with the environmental elements. Corals, passes, fish, sharks and many other animals of the lagoon are known and recounted from generation to generation. In the Kanak world, this knowledge relates to the world of elders as well as food, social or economic resources. It is acquired through the experience of each person and is therefore constantly renewed through regular, often daily, interactions. This experience includes practices and observations of the environment that guide fishing practices and trips on the lagoon.

*Box 29*

## Participative customary management works

*Luen Iopué, Maël Imirizaldu and Sophie Katrawi*


Yeega and Dohimen Marine Protected Areas in Hyehen commune. From DDEE-SMRA, Province Nord.

In New Caledonia, the four authorities (government and island, North and South Provinces) have jurisdiction over environmental management, which leads them to work closely with customary authorities. These stakeholders often play a central role in the co-management of maritime areas.

Even if they do not physically occupy the entire space (whether marine or terrestrial), communities maintain a special bond with it. This link can be the result of alliances, the supply of essential resources or simply a mythical one. It is a true bond that inspires the symbolic identity of the Kanak people, translates into a socialization of space and different lifestyles and is conveyed by legends, myths and practices.

The particular links that Kanak people have with the marine and terrestrial environments have been further described by various studies. In the Nouméa Accord and the preamble of the Organic Law, special attention is given to the integration of these cultural characteristics into the management of maritime areas.

The result of this is the participative management of New Caledonian sites. For instance, UNESCO requires the involvement of local communities in the management of World Heritage sites. In New Caledonia, the participation and involvement of customary communities has been pivotal.

This customary participative management must take into account several factors for the best possible implementation of the practices in the field. To quote the words of customary communities, "the souls of the elders watch over people and the implementation of their actions".

This requires the respect of a number of practices related to the Kanak culture. It is often described as "making a custom offering" ("faire la coutume"), but these few words cover several realities. A "custom offering" ("geste coutumier") is required as an introduction before establishing any action in a given place. This offering involves introducing oneself (showing one's face), bending down before asking to speak in order to express a request or to give responses, without offending the elders, and offering a gift related to this request (e.g., a yam, mat, etc.). It is the start of everything that is undertaken in the customary world.

Customary participative management also integrates a connection to space and time. Beyond the physical differences (land and sea, surface and contents), Kanak people consider their land as a whole (fauna, flora, biotope), from the crest line to the reefs, or even beyond the horizon line (d'Entrecasteaux Reefs are part of the Dau Ar/Belep chiefdom). This is why reefs often have vernacular names. Customary communities therefore have to include this reality in their management policy, and this is what the three provinces and the government of New Caledonia are trying to do.

However, the timeframe is often longer than usual. In a management framework, it is often necessary to adopt strategic orientations and actions to be implemented, which do not require the support of the majority but do need the consensus of all the families and/or clans involved. In doing so, the proposal must encompass all the "paths of alliance" or structures kinship for the decision to be taken. This speech journey is sometimes long, but it is necessary and in practice, solutions are found to facilitate it.

Traditional Kanak hut, tribe of Grand Atéou. © P.-A. Pantz

On New Caledonian sites, customary participative management works well. Communities ensure that customary aspects are taken into account in the management and implementation of actions, as is done in Australia, to some extent.

The New Caledonian management committees, in which customary communities are strongly represented, are the formalization of this consideration. In these committees, customary communities become important management stakeholders and they are recognized as such. Management committees meet every two years under the auspices of the Conservatory of Natural Areas (CEN: Conservatoire d'espaces naturels) to review the management of UNESCO World Heritage sites.

In addition, the customary senate has a representative on the CEN board of directors, a representative on the managment committee of the Marine Park of the Coral Sea and in other institutions dealing with environmental issues: the environmental advisory council (CCE: conseil consultatif de l'environnement), the economic, social and environmental council (CESE: conseil économique, social et environnemental), the area councils, and the youth councils.

Preparing a custom offering, Isle of Pines. © P.-A. Pant

## Knowledge that builds culture and rules

A customary reserve is an area closed to fishing on a temporary basis. With flexible spatial and temporal boundaries, it can be opened occasionally during customary or religious events. Access to the reserve may be dependent on kinship and a customary reserve is generally associated with a tribe, according to the logic of a territorial continuity between land and sea (box. 29).

Unlike a customary reserve, a taboo site is permanent. Access to a taboo site implies the observation of a number of rules, such as requesting permission from the tribe or associated clan and making a custom offering as a sign of respect for the ancestors or entities that populate the site. These places are named and have a history known to the knowledge "owner" and, hence, the site.

Those who have lived alongside the reefs for a long time have developed particularly precise knowledge of the reefs, knowledge that is an integral part of their history and culture. For Kanak people, as for other communities in the territory, this ecological knowledge is both the support and cement of their cultures. It is the basis of social relationships and pathways, links between individuals and between groups. It is linked to formal and informal rules for sharing territories and resources. These rules, and the customs associated with them, have a social function and can have beneficial consequences on the ecosystem, such as ensuring the good condition of a habitat or certain species of the lagoon.

## Integrating local knowledge into lagoon management

As part of the inscription of the New Caledonian lagoons on the UNESCO's World Heritage List, several management committees have been set up, bringing together all socio-economic and institutional stakeholders, as well as representatives of local populations.

If the green sea turtle *Chelonia mydas* is fully protected in New Caledonia, it is still possible to obtain exceptional hunting permits for customary ceremonies. This system of derogations has been set up to take into account the specificities of Kanak culture. Depending on the provinces, it may still be subject to adjustments and consultations with the customary senate, customary areas and populations, in order to refine the standards if it produces local misunderstandings or presents implementation difficulties.

For the Environmental Code of the Loyalty Islands Province, developed using a participative approach, co-construction of environmental rules is a pivotal aspect of the law. The aim is to reconcile customary practices and legal regulations stemming from the national "biodiversity law" of 2016 and international objectives. The provincial authorities can now delegate the power of managing the maritime zones that are within their area of influence to the customary authorities, thus ensuring that endogenous law is taken into account.

These examples show that, in New Caledonia, there are many instances where local knowledge meets official initiatives for the management of reef areas: hybrid management areas where MPAs (marine protected areas) overlap with customary reserves or taboo sites; the consideration of fishing practices to define the level of protection of the most socially emblematic species; and so on. This plurality ensures compliance with management measures by formalizing customary practices that are not necessarily known to all users.

This is very important because, in Kanak societies, the social and political organization is part of a territorial relationship that includes both land and sea. Customary areas extend from inland (from the peaks of the mountain chain on Grande Terre) to the reef and further offshore. The reefs, islets and remote islands are "marked" by names that testify of their appropriation, as well as of ancient practices that are still present in oral tradition.

Faced with the hybridity of areas and the plurality of customary functions and logics mentioned above, the law has to adjust for better environmental protection, as seen in the Loyalty Islands Province.

## Engaging knowledge dialogue

In New Caledonia, social science's study of the relationships between societies and their environments (and thus of how they "manage" the areas called "reef ecosystems" by scientists) is often interdisciplinary (involving not only anthropologists, geographers, socio-economists, jurists but also ecologists and biologists) and in direct contact with users and keepers of the local knowledge. This overlap between different forms of knowledge produces useful results for the implementation of informed negotiations between inhabitants and decision-makers, without which it would be difficult to conceive appropriate, accepted, acceptable and sustainable natural resource governance policies.

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*Chapter 43*

# Towards planned management of reserves in New Caledonia

*Laurent Wantiez, Emmanuel Coutures, Maël Imirizaldu, Michel Kulbicki and Laurent Vigliola*

Juvenile Napoleon fish *(Cheilinus undulatus)*. This species, classified as endangered by the IUCN, is found in protected sites. © IRD/S. Andréfouët

Coral reefs are one of the most threatened ecosystems on the planet. They are confronted with the combined effects of global climate change (warming, sea level rise, ocean acidification) and local environmental changes linked to local human activities (growing demographics, fishing, pollution, habitat degradation). These pressures add to natural disturbances (tropical cyclones, acanthaster outbreaks, etc.), whose destructive dynamics are amplified by the environmental changes induced by human populations. The conservation of this ecosystem and the preservation of the resources and services it provides have therefore become major challenges, which often involve controlling the exploitation of resources (species, their size, fishing gear and harvesting season) or establishing marine protected areas (MPAs).

New Caledonia hosts the world's largest lagoon around the main island, Grande Terre (19,385 km$^2$), the second largest barrier reef (1,600 km long) after the Australian Great Barrier Reef, and one third of the world's most isolated and preserved reefs. Therefore, their environmental protection is fundamental at both local and global levels.

In New Caledonia, the implementation of protective measures has been gradual and pragmatic. It was carried out concomitantly to the increase in anthropogenic pressures and the observation of the first impacts, particularly the decline in resources (fishing) and the direct or indirect degradation of the reef and lagoon environments (from mining and urbanization). The implementation of the first protective measures

in the 1970s followed a "wise pragmatism" approach, responding to a determination for action despite the lack of knowledge. The New Caledonian coral ecosystems would probably not be as healthy today if this pragmatism had not triggered and fueled local conservation policies. With time and the acquisition of new knowledge on the dynamics of systems, these policies gradually evolved towards a truly planned management strategy.

The natural protected area is one of the most commonly used protection tools in New Caledonia. It complements resource regulations through the protection of biodiversity within its environment. This type of protection is familiar to the New Caledonian people because it involves the use of various historical forms of "customary/traditional reserves", which are common in Oceania. These customary reserves are now being gradually integrated into "contemporary" marine protected areas. The success of this tool lies in the relative simplicity of its management and its proven effect on protected resources, particularly on harvested species.

## The "reserve" tool in New Caledonia

The first protective measures were implemented by confronting the conservation objective (the reserve as a "larder") with expert analysis.

The first significant action was the creation of the Merlet Reserve in 1970 (box. 30). This initiative can be commended for several reasons. First, it was established at a time when the conservation of New Caledonian reefs was not a priority. Second, it is large (173 $km^2$) and benefits from the maximum level of protection (strict nature reserve). Lastly, its protection level has been maintained until today with increased surveillance facilities and regular monitoring of its health status.

The second milestone was the creation of the reserves of the "Grand Nouméa Park" ("Parc du Grand Nouméa"), formerly known as the "South Lagoon Park" ("Parc du lagoon sud"). These protected areas are regulated marine reserves where access is permitted, but any harvesting is prohibited. The origin of this awareness was the impact of fishing on coral reef resources near Nouméa, where the density of users and the resulting boating pressure are the highest. The initiative involved two phases. The Amédée lighthouse and Maître Islet have been protected since 1981 and four other islets since 1989 (Bailly, Canard, Larégnère and Signal). The year 1990 marked the real beginning of conservation programs with the launch of the first surveillance vessel, the Isabelle. At the same time, and since 1994, regular monitoring (every four years) of the evolution of these reefs has been undertaken to quantify the success of these actions. Their status then evolved into Sustainable Resource Management Areas (SRMAs) or nature reserves, according to the uses and possible economic activities that developed there. Seasonal reserves were also set up to protect fish aggregation sites for spawning, such as the Dumbéa Pass or Grand Port in Prony Bay. However, some inefficient initiatives were discontinued, including the rotating reserve of the three barrier reefs facing Nouméa (Mbéré, Aboré and Kué), where each reef was successively protected for three years.

Although the first regulatory tools for the protection of natural areas were set up around the capital, this type of protection has always been employed by indigenous populations in their so-called "customary reserves" (box. 29). The creation of these protected community areas is linked to the original perception of the clans of the sea that the lagoon is their property. Their main vocation is to protect "their own" resources, particularly so that they are available during major customary ceremonies or special community events. This is probably why the Northern Lagoon (Grand Lagon Nord) is one of the most exceptional reef formations in the territory today. Over the last decade, this customary protection, which also has a subsistence objective (food and artisanal fisheries), has evolved towards an acceptance of the need to adapt and integrate into the rules of common law (regulated protection). The associated objectives have evolved from the protection of resources ("larder") to the conservation of ecosystems for economic valorization (ecotourism). This evolution has led to the creation of the Pweevo and Hyehen reserves on the northeast coast and discussions are under way on the creation of a reserve around Ouvéa Island (Uvea/Iaai).

The strict nature reserve of Merlet. © P.-A. Pantz

*Box 30*

## The Merlet Reserve, the jewel of the South Province

*Emmanuel Coutures*

Located between the Sarcelle and Havannah passes, the strict nature reserve, Yves Merlet, created in 1970, is a sanctuary for both the terrestrial and marine flora and fauna of the Southern Lagoon. This maritime space of 17,200 ha, which includes the islets of Améré and Kié, was already covered by customary management when it was formalized by a palaver transcript between the Goro chiefdom and the territorial office of the merchant marine.

Now integrated into the provincial marine park of the Grand Lagon Sud (part of the property inscribed on UNESCO's World Heritage List), the "Merlet Reserve" aims at maintaining the wild state of a reef and lagoon area with a minimum of anthropogenic activity.

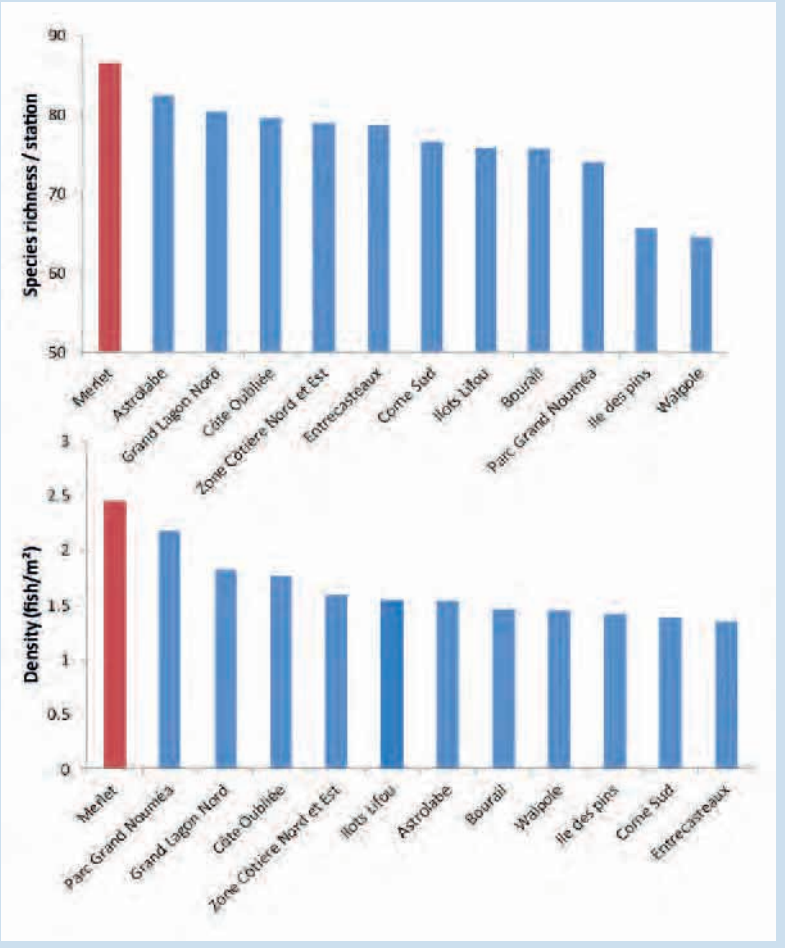
The level of protection of this sanctuary has increased over time: the derogations for the organization of customary fisheries (*mikwaa* or milkfish *Chanos chanos* and green sea turtles), which are still provided for in the South Province Environmental Code, have not been implemented for nearly 10 years.

The reserve is subject to specific management measures. Authorizations to enter the Merlet Reserve for scientific purposes (collection of samples) are increasingly rare and constrained.

Due to its status and the diversity of its coral communities, the Merlet Reserve was chosen as a site for monitoring the Grand Lagon Sud Marine Park. Between 2008 (initial state) and 2013, the monitoring revealed a very healthy ecosystem with no significant anthropogenic impact (WANTIEZ *et al.*, 2013). It hosts the largest diversity (more than 100 species/site) and density (more than 2.3 fish/m$^2$) of reef fish measured as part of the New Caledonia reef monitoring. Giant clams are also very frequently observed (95% of sites) and numerous (4.9 individuals/250 m$^2$), and the trochus are relatively large (9.7 cm on average). Emblematic species are common, including sea turtles and Napoleon fish.

Rangers carry out between one and five inspections of the Merlet Reserve per month, either by day or night, and only record five to six offences per year.

Over time, the Merlet Reserve has become the reference point in discussions relating to the environmental and societal importance of areas with enhanced protection from human pressures. It is both a source of pride for all New Caledonians and a treasure pampered and fiercely protected by the South Province.




Number of species by site and fish density at major coral sites monitored in New Caledonia between 2012 and 2014. © UNC/L. Wantiez

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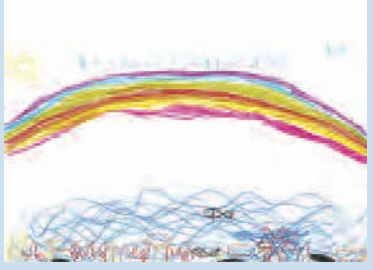
*Box 31*

# What is the reef in the eyes of the children of New Caledonia?

*Jocelyne Ferraris, Georgeta Stoica, Catherine Sabinot, Pascale Chabanet, Stéphanie M. Carrière, Claire Levacher and Marlène Dégremont*

Influence of the socio-cultural and environmental context on the perception of coral reefs (after using the MARECO case).
A: Yaté, "Wadiana waterfall". © J.-B. Agourere
B: Nouméa, "The coral reef". © M. Meray



Drawings before (left) and after (right) the use of the MARECO case, "The reef in our hands", by Marie-Louise, eight years old, Isidore Noell school. © M. L. Xowi

In 2016, about 80 children from five primary schools in Nouméa (Boyer, Isidore Noell), the east coast (Thio and Yaté) and the mountain chain (Coula) participated in an interdisciplinary research program on the perception of coral reefs. This program was led by a team of natural and social science researchers. Its aims were to assess the knowledge, practices and perceptions related to coral reefs in children aged between six and eight years old and to develop a method to evaluate the impact of an awareness campaign on reef vulnerability in four French regions (New Caledonia, Mayotte, Reunion Island and Pyrénées-Orientales).

## Exploring the coral reef ecosystem is fun!

Coral reef drawings were collected before and after the use of a "The reef in our hands" kit containing three educational games whose objective was to communicate scientific concepts on biodiversity, disturbances, uses and management methods of the coral reef ecosystem. A total of 1,300 drawings and interviews conducted in the field, were analyzed using a grid listing and coding of the depicted elements, in order to compare the coral reef perceptions of the 20 primary school classes involved in the program.

## When science meets education

The analysis reveals a great diversity of perceptions among children according to socio-cultural profiles, but also between urban, rural and coastal environments. This emphasizes that relationships with nature or the environment vary from one school to another, depending on direct and indirect experiences of the reef. Using the MARECO case results in an improved understanding of reef biodiversity. The immersion of scientists in the school environment also improves understandings of academic and empirical knowledge and their plasticity in different contexts, as well as how they are transferred, in order to maintain, disseminate and improve them.

Modernity is marked by the gradual transition from the "wise pragmatism" of the beginnings to planned management, including the adoption of an Environmental Code by all provinces. Two major initiatives also reflect the growing and recent awareness of protection and the stakes involved in conservation: the inscription of the "Lagoons of New Caledonia" on the World Heritage List in 2008 (15,743 km$^2$; chap. 46) and the creation of the Natural Park of the Coral Sea in 2014 (1,291,000 km$^2$; box. 5). These two major initiatives commit New Caledonia to long-term responsibility for conservation. They will only be successful if they are supported by a strong and well-established management policy, as well as the implementation of appropriate resources and coherent governance.

## The success of pragmatic management

The success of the pragmatic use of the "reserve" tool in New Caledonia is based on a series of decision-making processes:

– setting realistic objectives;

– the choice of a suitable strategy and tool based on available knowledge;

– regular assessment of the outcomes to enable informed decision making and regular adaptation of management strategies and objectives.

It is now recognized that well positioned and monitored marine reserves have many positive effects on protected communities. These effects have been checked and demonstrated on numerous occasions in New Caledonia.

In the reserves of the Grand Nouméa Park, fish communities developed very rapidly after the implementation of monitoring measures and reached spectacular levels in just four years. The number of edible fish species increased by 67%, their density by 160% and biomass by 246% (WANTIEZ *et al.*, 1997) (Fig. 1). At the same time, the number of species and biomass at unprotected sites did not change and the density increase was twice as low. Since 1994, changes in the protected fish populations have been mainly the result of natural causes (Fig. 1). They develop when environmental conditions are favorable and are particularly affected by disturbances (tropical cyclones). The global oceanographic climate (El Niño/La Niña) also seems to affect these communities.

Another typical example is the lobster populations in the Ouano Reserve. None were observed in the reserve and adjacent monitored unprotected areas before the reserve was created and for seven years after monitoring began. From 2014 onwards, lobsters became frequent in the Ouano Reserve (over 50% of sites) while they are still absent from unprotected areas, although favorable habitats are available (WANTIEZ *et al.*, 2015). Thanks to these protected areas, the emblematic Napoleon fish has also returned.

The protected areas thus allow protected communities to develop. In the long term, they also have an "overflow" effect, with specimens moving from the protected area to adjacent unprotected areas, a phenomenon which was documented in the Grand Nouméa Park for commercial fish species (coral trouts, groupers, parrotfish) (CHATEAU and WANTIEZ, 2009). These effects have probably also occurred in all other protected areas of the territory, for which no pre-protection monitoring data exist.

## The limits of New Caledonia's reserves

Marine reserves are an effective tool. However, like any tool, they have their limitations and cannot solve all problems on their own. Marine reserves must evolve with knowledge and adapt to contemporary environmental and societal challenges.

The monitoring of protected reefs in New Caledonia revealed that reserves could do nothing to protect against major meteorological events (e.g., tropical cyclones). These events have an immediate and devastating effect on coral habitats and their associated species. A tropical cyclone can destroy years of protection efforts. For example, in 2003, the tropical cyclone Erica had immediate and significant destructive impacts on the entire ecosystem of the Grand Nouméa Park, resulting in a complete change of community structure. This

was still significant in the medium term (two years) (WANTIEZ *et al.*, 2006) and complete restoration occurred only in the long term (10 years) (WANTIEZ *et al.*, 2014). When the ecosystem is particularly vulnerable, the time required for restoration is dependent on the absence of further disturbance during the process. Hence, reefs recovered in Nouméa, but not in Ouano, where strong westerly swells in 2008 and 2009 destroyed the first signs of coral habitat recovery (WANTIEZ *et al.*, 2015).

In addition, protecting an area leads to the geographical transfer of the fishing effort, which increases in unprotected areas as a result. In New Caledonia, this happens in a context where the pressure exerted on reefs (fishing and non-extractive uses) is increasing. If too many reefs are protected in a densely populated area, the effects on coral reefs, as a whole, may be more negative than positive. It is necessary to optimize the balance between protected and unprotected areas according to the population and to provide the necessary means to control catches. An alternative to this would also be to develop non-extractive economic activities in order to reconcile economic development and environmental protection. However, non-extractive uses also need to be regulated to minimize their environmental impact. For example, a reserve where all harvesting is prohibited but access is allowed, attracts people who come to observe healthy reef communities (e.g., large fish). These areas can then attract a population that exceeds their carrying capacity. This is very obvious on sunny weekends when large numbers of boats aggregate in the reserves of the Grand Nouméa Park.

When properly designed and monitored, marine protected areas are often presented as the ideal tool for conservation. However, despite effective protection, this tool does not allow the coral ecosystem to recover all the characteristics of a system devoid of any negative impact (D'AGATA *et al.*, 2016). This is well illustrated in New Caledonia by the Merlet Reserve, whose results do not reach those of the most remote reefs (d'Entrecasteaux, Astrolabe, Pétrie, Chesterfield, etc.). The most significant differences are in the case of large predators such as sharks (JUHEL *et al.*, 2018), as well as species with high commercial value such as giant clams and sea cucumbers.

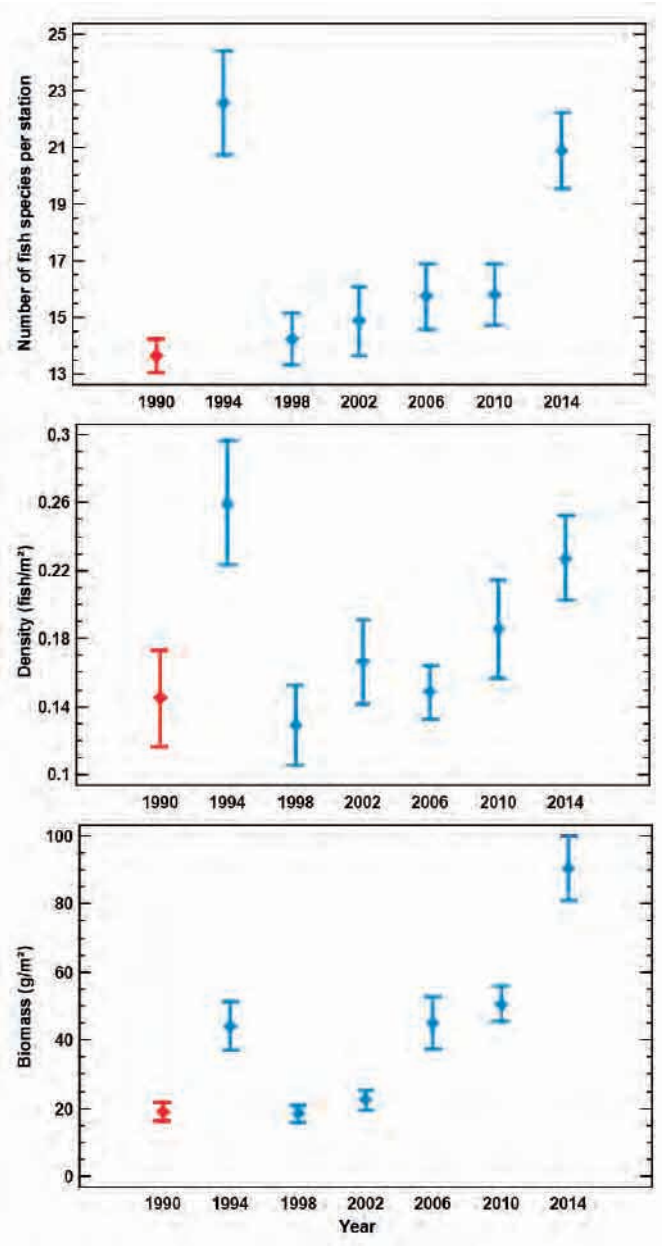
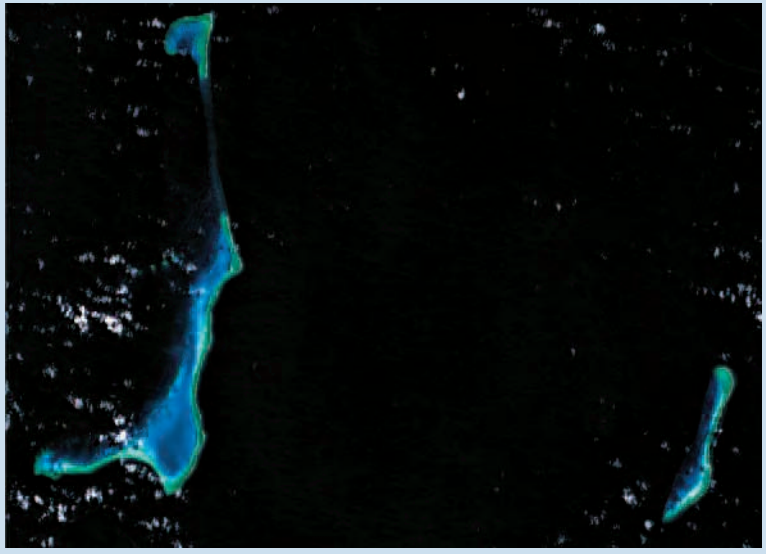



Figure 1: Variations (± standard error) in total species richness, site species richness, density and biomass of commercial fish species in the five reserves of the Grand Nouméa Park, before (in red) and after (blue) the implementation of monitoring actions. Adapted from WANTIEZ *et al.*, 2014

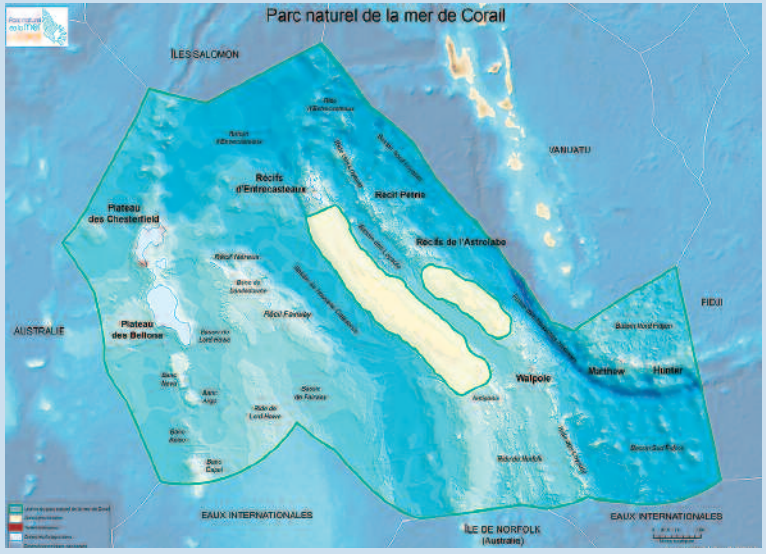
*Box 32*

## Isolated reefs will soon be highly protected

*Marie-Hélène Merlini and Julie-Anne Kerandel*



Satellite view of Astrolabe reefs (Sentinelle 2 image, march 15th 2018)




Natural Park of the Coral Sea. © Gouvernement de la N.C/DAM-NC/SPE

Only 1.5% of the world's reefs are considered "untouched" by any human impact. The Natural Park of the Coral Sea hosts 30% of these reefs.

### Pétrie and Astrolabe: exceptional reefs

The reefs of the natural park that have already been studied are among the richest in the world and described as pristine by the scientific community. The Pétrie and Astrolabe reefs, for example, host one of the highest reef fish biomass in the world and rank higher than the largest marine reserve in the Chagos Islands (Indian Ocean). Chesterfield and d'Entrecasteaux reefs also surpassed Kingman Reef, which used to be the global reference point for "virgin" sites in the Pacific. These comparative studies ("PRISTINES" and "PRISTINES SEAS" projects), carried out in 2012 and 2013, provided an understanding of the value of regulating access to the most remote areas of ecological interest.

### D'Entrecasteaux, a challenge for protecting biodiversity

Since April 23rd 2013, the government of New Caledonia has clearly stated its intention to protect the environmental jewels of its maritime space by establishing a protected area in the atolls of d'Entrecasteaux, the first natural reserve in the waters under its jurisdiction. The Le Leizour Islet and the vegetated part of the

Surprise Islet are classified as a strict nature reserve. All other emerging zones, waters and seabed included within the protected area of the d'Entrecasteaux Atolls are classified as nature reserves. Across the protected area, activities related to professional fishing are prohibited and access to the area is restricted.

## Turning isolated reefs into sanctuaries, one of the first management priorities

One year later, on April 23rd 2014, the Natural Park of the Coral Sea was created, confirming the energy for conservation and the protection of all reefs, even those far removed from the New Caledonian maritime space. Although it is recognized that the remoteness of coral reefs forms a natural protection, planning a management strategy is an absolute necessity. In the management plan of the Natural Park of the Coral Sea, the first objective, dedicated to natural and cultural heritage, is to "protect ecosystems and their connectivity", and particularly to "protect remote reefs". This objective requires a high level of protection for remarkable areas (pristine reefs). By mid-2018, all "pristine" reefs (Chesterfield-Bellona and Petrie-Astrolabe) will be protected by the government.

## Maintaining the life cycle

A high level of protection would help the conservation of ecosystems. For example, these reefs are used as breeding and feeding grounds by reef and tiger sharks. It is also likely that large predatory sharks use the Chesterfield-Bellona zone as a stopover for annual migrations between New Zealand and the tropical zone. Coral reefs are unique ecosystems essential to the life cycle of species, and to ensure the safety of an abundant and balanced marine life. Establishing regulations and providing the necessary means for their implementation is a visionary and responsible long-term strategy.

Today, conservation measures mainly target coral reefs, which represent the country's emblematic marine ecosystem. This approach has its limitations because it does not take into account the entire reef and lagoon environment, which functions as a connected network of fragmented ecosystems. Reef conservation therefore requires the consideration of wider geographical scales and even the entire seascape. The "informed management" process, which is being gradually adopted in New Caledonia, will have to consider this constraint and significant efforts will have to be dedicated to the protection of mangroves, seagrass meadows and lagoon soft bottoms, which are poorly taken into account today. The situation is similar for seamounts, located at the interface between remote reefs and those closer to Grande Terre, as well as deep and coastal, and pelagic and reef ecosystems.

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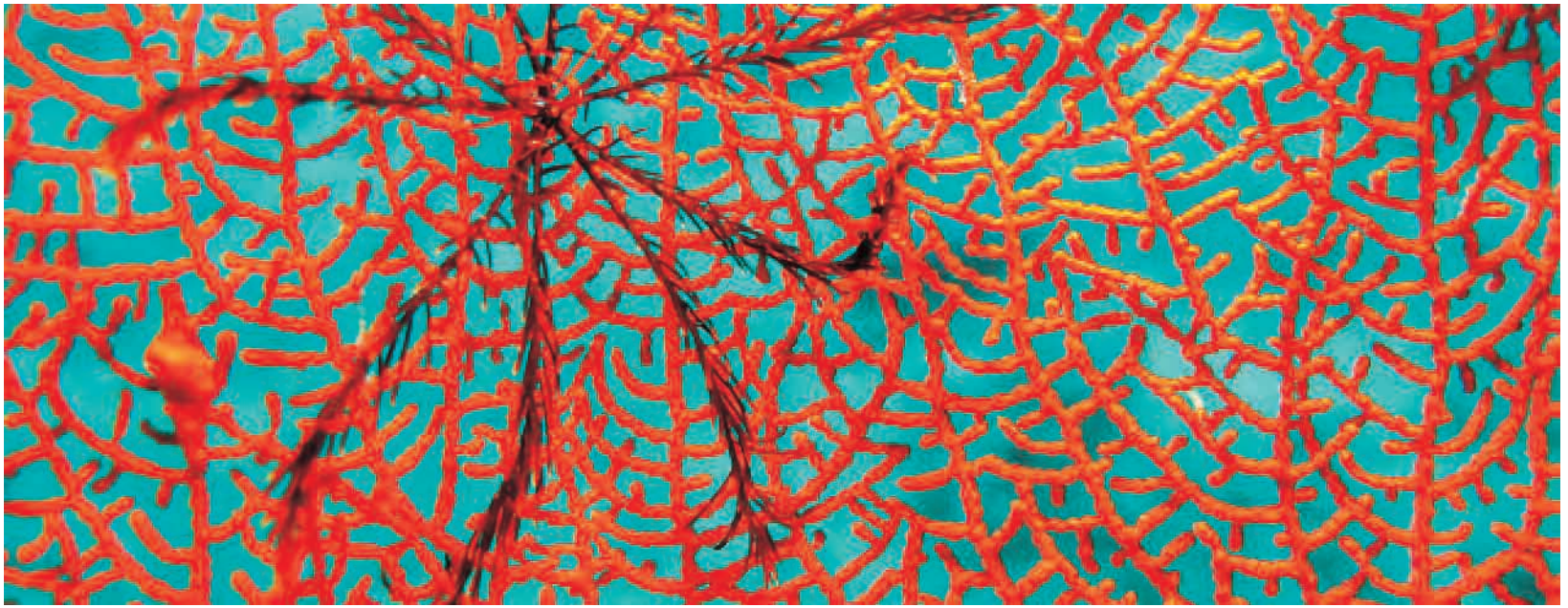
*Chapter 44*

# The challenges of modelling coral reef ecosystems

*Morgan Mangeas, Antoine Wickel, Jean-Brice Herrenschmidt, Catherine Sabinot, Pierre-Yves Le Meur, Laurent Vigliola and Gilbert David*



Gorgonian and feather stars, east coast, 2012. © IRD/J. L. Menou

Coral reef ecosystems are complex and their health relies on a balance between the composition of the associated fauna and flora, and the environment. When they are healthy, coral reefs perform many functions that translate into "ecosystem services". They contribute to the well-being of local communities and participate in coastal economic development. Coral reefs support recreational and tourism activities, produce biomass that contributes to economic development and food security through fishing, and provide other services such as protection from wave action and carbon sequestration. These ecosystems also have high symbolic and identity values, and their cultural and heritage aspects are essential at local, national and international levels.

Modelling (box. 33) coral reef ecosystems and the pressures they are exposed to, as well as the interactions with human populations and the links to ecosystem services, is, therefore, a real challenge. The stakes are high: modelling coral reef ecosystems provides a better understanding of the internal and external rules by which they are governed, as well as a detailed analysis of the relationships between the fundamental elements they consist of. Modelling can also estimate the responses of the coral reef ecosystem to different scenarios of future environmental and human pressure. In addition, by including control variables in the model it is possible to determine which combination of actions can be effective for ecosystem stabilization and to avoid major degradation.

*Box 33*

## What is modelling?

Modelling involves defining a set of equations or rules intended to describe a phenomenon and its dependencies in a reproducible and simulated way. A model is used to predict the response of a system to known stresses. Modelling generally requires a calibration phase, which involves estimating a set of parameters so that the model's response is close to what would be expected by experts or reproduces past observations.

There are several types of models and a distinction can be made between "mechanistic" and "statistical" approaches. The mechanistic approach equates the biological, ecological or physical mechanisms that induce the dynamics of the studied phenomenon. The statistical approach builds on the data available to determine a function capable of "approximating" the interactions between the variable to be explained (the phenomenon) and the explanatory variables (the factors that influence the dynamics).

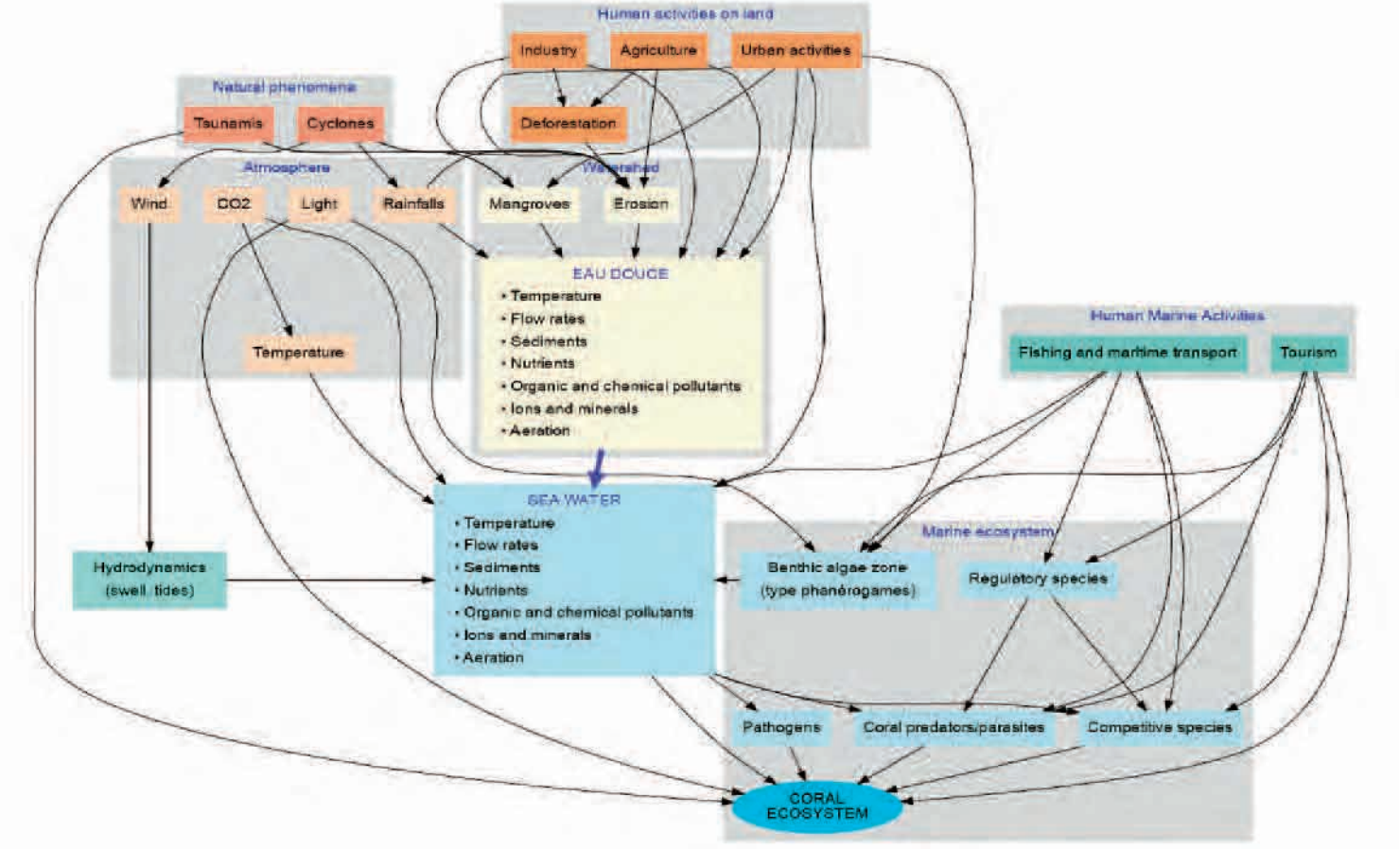



Figure 1: Relationship between the main stressors of the coral reef ecosystem, their potential impacts and the indicators used for assessing the state of the environment. Arrows describe the known relationships between these different elements. © IRD/M. Mangeas

As is often the case with complex ecosystems, the modeler is confronted with spatial and temporal scale issues. Some pressures can be occasional, such as an industrial chemical spill in the lagoon, which massively disrupts the coral reef ecosystem in the very short term. Others can act over several decades, such as the slow rise in seawater temperatures (+0.7°C on average since 1990), which strains the adaptive capacity of the flora and fauna of coral reefs. Similarly, at the spatial level, modelling processes limited to coral colonies will require detailed and highly localized information, which is not available at the scale of a reef of several square kilometers. Model design therefore depends on the nature of the phenomenon under study and the spatial and temporal scales of the relevant and available data. Lastly, a problem-oriented model always represents a compromise between complexity, robustness and the ability to simulate observations

## Pressures and impacts

The Knowledge Representation Model of pressures (ICRI, 2016) that impact the health of a coral reef ecosystem (Fig. 1) is the first step in a modelling process. However, there are still many grey areas around abiotic (physico-chemical conditions) and biotic (species interactions) factors that maintain coral systems in a healthy state. This makes it difficult to translate them into equations. Although they are necessary to statistically estimate the relationships between the various components of the ecosystem, there are very few datasets that simultaneously characterize the state of the environment and the health of the coral reef ecosystem.

It becomes even more complex when the health of the coral reef ecosystem is linked to socio-economic factors and coral reef-induced services (Fig. 2). We observe that, if the health of the coral reef ecosystem deteriorates, ecosystem services are affected and users are likely to act accordingly (fewer tourists, fewer fish, recreational activities are less attractive, etc.). If this happens, users will exert pressure on public authorities to implement protective measures. This therefore gives rise to the hypothesis of a dynamic system, structured by a feedback loop and self-regulation between users and the coral reef ecosystem.

This complex issue was recently addressed as part of the CORAIL research project, funded by the European program BEST and conducted in New Caledonia and French Polynesia, between 2013 and 2016. Research institutes, organizations and consulting agencies involved in this project worked in collaboration with local decision-makers and stakeholders to apprehend and co-construct methodological developments and public policy tools for the management of coral reef ecosystems. The study sites were the southern region (Grand Sud) and Hienghène for New Caledonia, and Opunohu and Moorea in French Polynesia.

## Bayesian networks

A Bayesian network (KJAERULFF and MADSEN, 2007) is a probabilistic graphical model, representing random variables in the form of an acyclic oriented graph. Its networked architecture transcribes almost directly the models of knowledge representation such as those described in Figures 1 and 2. The cause-effect relationships between variables are not deterministic in this type of modelling, but probabilistic. Thus, the observation of a cause or several causes does not systematically lead to the effect or effects that it triggers, but only modifies the probability of observing them. Bayesian networks are particularly interesting because they simultaneously take into account the a priori knowledge of experts and the information contained in the data. Bayesian networks are mainly used for risk analysis and to support decision-making. Mathematically, the states of variables representing nodes in the Bayesian network are assessed using conditional probability calculation techniques and the Bayesian theorem (box. 34).

For example, a simplified Bayesian network can model interactions between coral reef ecosystems, induced ecosystem services, human pressures and natural disturbances (Fig. 3). Although this model has been successfully tested in other parts of the world, its application in New Caledonia is difficult due to a lack of data. However, one of the advantages of Bayesian networks is that a model can be built based on expert knowledge. It was possible to calibrate a model for targeted areas of New Caledonia using the knowledge of researchers,

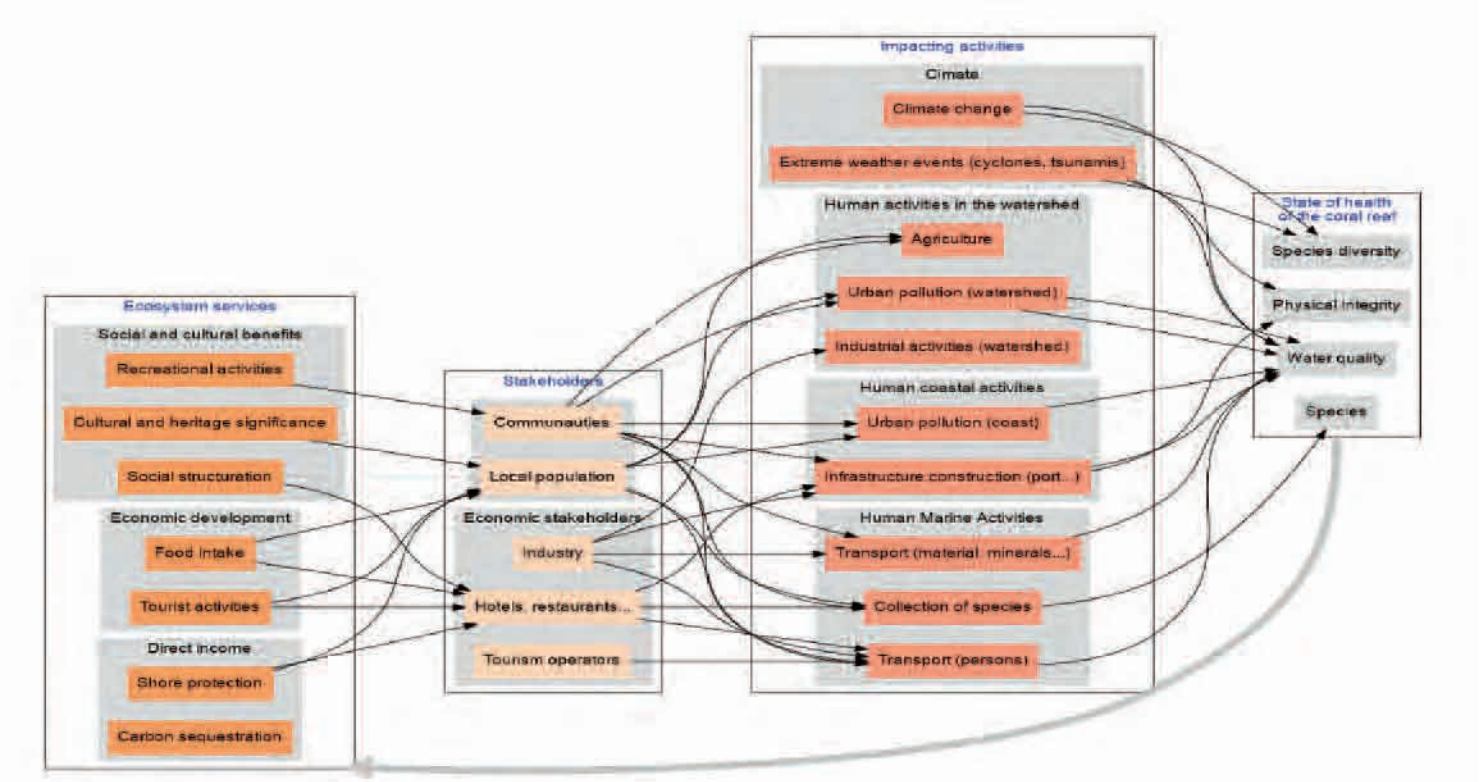



Figure 2: Interactions between users, ecosystem services, pressures on the coral reef ecosystem and potential impacts. The arrows describe the known relationships between these different elements. © IRD/M. Mangeas

inhabitants, lagoon users and stakeholders involved in environmental management.

Feedback modelling would require the use of a more complex model such as a Dynamic Bayesian Model (DBN). However, this simplified approach identified the main trends and proposed scenarios that can then be used to guide the management of coral reef ecosystems in the study area.

## Study site

Yaté is a municipality of New Caledonia located in the south of Grande Terre, 80 km from Nouméa (Fig. 4). Its surface area is significant (ranked the 15th largest municipality of France) given the small number of inhabitants (less than 2,000). The population mainly inhabits the narrow coastline where traditional fishing is practiced on the reefs facing the municipality. However, since 2009, one of the world's largest nickel mining plants has been built and is operated by the Brazilian mining operator Vale. The lagoon and coral reefs of the municipality are subject to several forms of pressure yet still thriving, but the population has largely abandoned fishing for mining jobs. The situation in New Caledonia is a typical example of multi-stakeholder negotiations involving diverse issues (environmental risks, mining industries, food uses, etc.). Negotiations on environmental management and the offsetting of mining impacts are very active, sometimes conflicting and often mediatized. The available socio-economic data are provided by the ISEE (Institute of Statistics and Economic Studies of New Caledonia), spatial data by the geographical portal of New Caledonia (www.georep.nc) and biological data by l'OEIL (Environment Observatory in New Caledonia, www.oeil.nc).

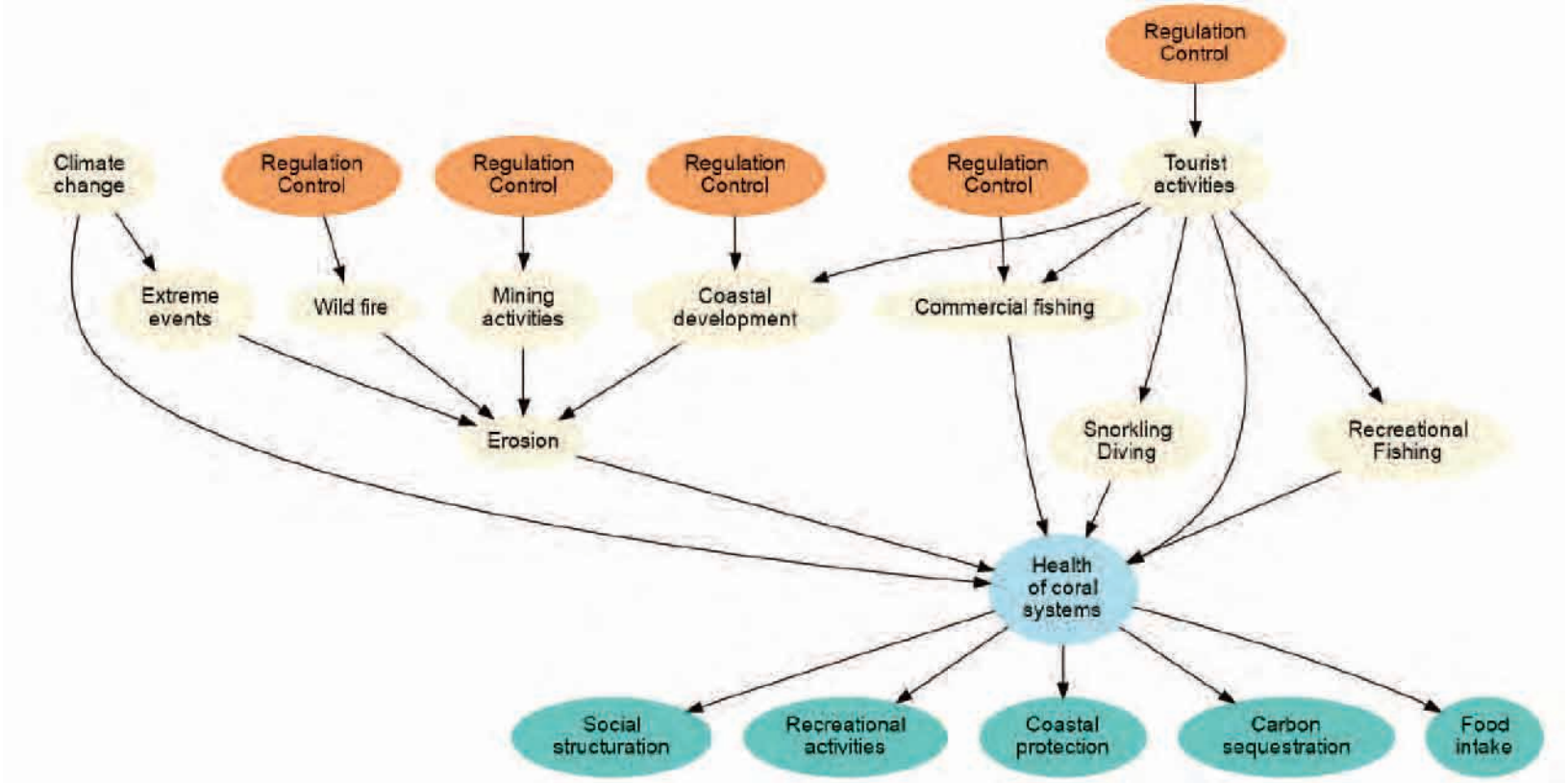
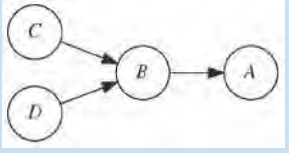



Figure 3: A simplified Bayesian network. © IRD/M. Mangeas

*Box 34*

## The Bayesian theorem




Suppose that each of the four variables A, B, C, D evolves in a set of three states: "strong", "medium", "weak". Conditional probabilities are written as:
P(A = "strong" | B = "weak")

This literally means: probability that A is in the "strong" state, knowing that B is in the "weak" state. In a Bayesian network, if all the conditional probabilities associated with the relationships are known, either by statistical estimation or via an expert opinion, it is possible to calculate the probability that one of the variables is in a certain state according to the known states of the other variables. For example, it is possible to calculate by domino effect P(A = "strong" |C = "strong" and D = "medium") even if the state of B is unknown.

Note that it is possible to estimate the probability of a variable being in a certain state, even if it is a cause and the consequence is known. For example, P(B = "weak" |A = "strong") is calculated using the famous Bayes theorem that calculates P(B|A) from P(A|B), P(A) and P(B):
P(B|A) = P(A|B)P(B)/P(A).

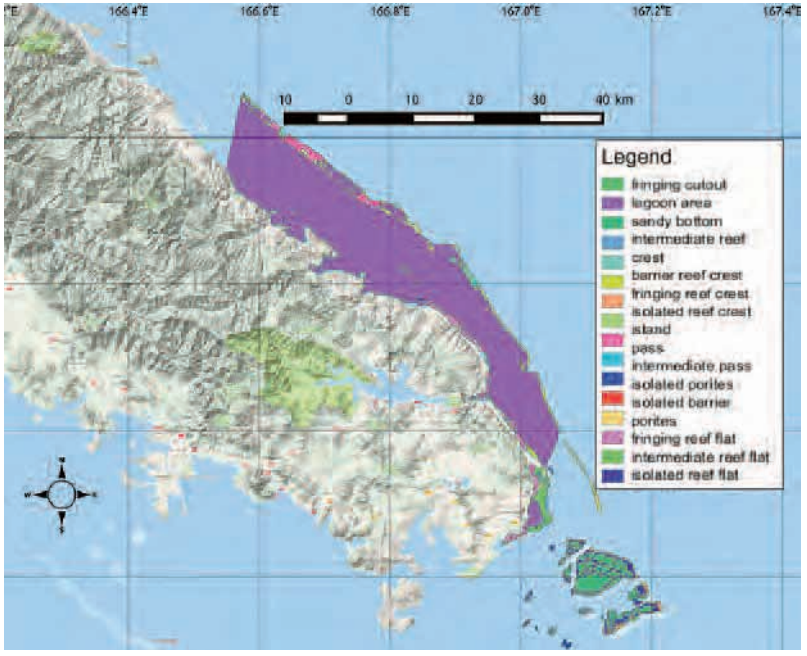



Figure 4: Study sites in the south of Grande Terre, New Caledonia. © IRD/M. Mangeas

## The scenarios studied using modelling

The simplified Bayesian network was calibrated to provide satisfactory answers regarding the needs and the current state of health of the coral reefs in the municipality of Yaté. The various pressures were also assessed and the impacts estimated by experts. The aim is to use the model to provide trends for four specific configurations. The four scenarios, which correspond to contrasting but possible situations in this region, are as follows:

– 1: Current scenario: reef and ecosystem services under the human and natural pressures of recent years;
– 2: Establishment of a strict nature reserve in the intertidal and subtidal zone of the lagoon of the municipality of Yaté corresponding to the IUCN protection level I.a.;
– 3: Closure of the Vale plant: mining activity is interrupted, resulting in the dismissal of employees who have to move to new jobs;
– 4: Population growth in the surrounding villages (strong urbanization): massive influx of population into the area.

The coral reefs in the municipality of Yaté are currently considered to be in good health (scenario 1), particularly far from residential areas where the population is sparse. This indicates that regular human and industrial activities in the area have had little impact on the ecosystem to date. However, this does not take into account the possible occasional pollution that could be caused by an industrial spill; such as a malfunction of the nearby marine outfall, which drains the water coming out of the metallurgical plant from the port of Prony into the Havannah Channel. This outfall raises the majority of concerns regarding potential impacts on the ecosystems of the Yaté lagoon.

The resulting model projections for coral reef ecosystem health and recreational activities are shown in Fig. 5. In the case of scenario 2, the IUCN's protection level I.a. requires a ban on all harvesting in the area and the model predicts that ecosystem health will improve. In the event of plant closure (scenario 3), the model predicts that the ecosystem will deteriorate due to inhabitants returning to a more marine-oriented subsistence lifestyle. Lastly, in the event of accelerated urbanization of the area (scenario 4), the high recreational use of the lagoon, coastal development and pollution linked to a high density of inhabitants could have a significant impact on the reefs in the area. On the basis of the available data, the model therefore suggests that a significant increase in attendance would have a stronger impact than the current "ordinary" mining activities (excluding pollution events caused by industrial spill). However, this model was adjusted based on very fragmented data, particularly regarding the indirect and long-term environmental impacts of the mine and plant on all components of the coral reef ecosystem.

One of the major advantages of modelling is the possibility to analyze all situations resulting from the factors used in the model. It is possible to test scenarios combining the "establishment of a reserve" and "plant closure" or "plant closure" with "heavy urbanization". With Bayesian networks it is also possible to identify the most likely cause of an improvement or degradation of the ecosystem, depending on the area and the intensity of the event.

Modelling coral reef ecosystems and the pressures to which they are exposed is highly complex. Societal changes are particularly difficult to apprehend, much more than direct measurable impacts, and just as much

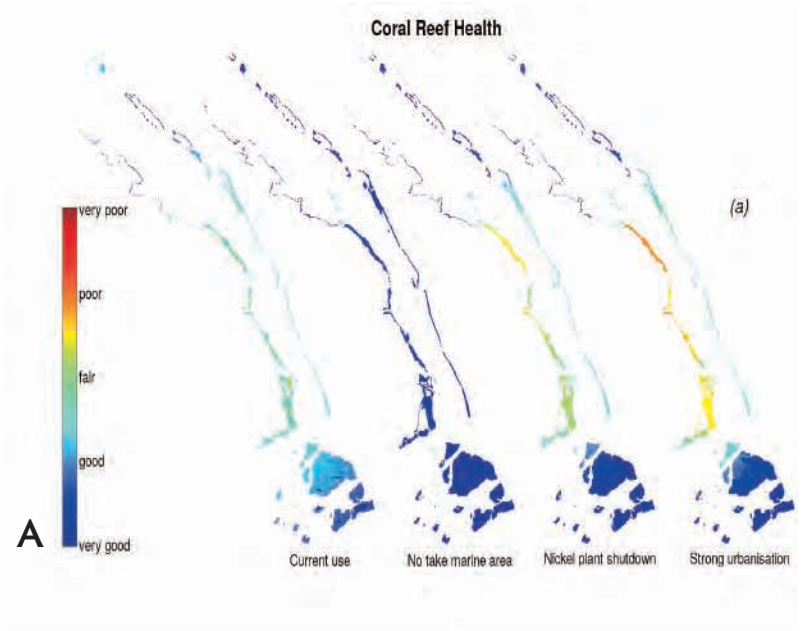



Figure 5: Municipality of Yaté, spatial assessment and evolution under the three scenarios studied.
A: Spatial assessment of coral reef ecosystem health.
B: Spatial assessment of recreational activities in the lagoon. © IRD/M. Mangeas

Mining processing plant, Vale, Prony. © P.-A. Pantz

as indirect impacts with their multitude of interactions between species and environmental variables. In the absence of a series of observations that are sufficiently long and accurate, modelling is highly dependent on expert knowledge. It also requires a multidisciplinary approach to determine the biological, societal and environmental interactions that influence the state of coral reefs and determine their ability to produce ecosystem services. In the case of the municipality of Yaté, because of the uncertainties surrounding the results, modelling is more suited as a tool for consultation and analysis than for prediction. In addition, modelling is not an end in itself; for it to be useful, it must become a user-friendly and efficient management tool so that stakeholders and decision-makers can use it in concerted decision-making processes.

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*Chapter 45*

# The law applicable to coral reefs of New Caledonia

*Victor David*


Southern Province protected area, Larégnère Islet. © IRD-ENS/T. Berr

The reader may be surprised to discover that there is no specific law applicable to coral reefs in New Caledonia! In fact, unlike other ecosystems and despite their importance (several points of view have been widely developed in this book) and their extreme vulnerability to natural threats and anthropogenic pressures, with only a few exceptions there is no binding law related to coral reefs ("sea rainforests") at an international, national, regional or New Caledonian level. Before proceeding further, it is important to clarify the concepts of hard law and soft law.

Hard law refers to binding legal texts. In the context of international law, hard law includes international treaties or agreements, as well as international customary law, which create binding obligations and rights for parties (states) and other international entities. Failure to comply with these obligations may result in the prosecution of the party before international courts.

Soft law refers to rules that are neither strictly binding in nature nor completely devoid of legal meaning. In the context of international law, soft law refers to agreements that establish guidelines, political declarations, action plans, strategies, guides to good practice or codes of conduct that set standards. However, they are not directly applicable and their non-compliance may not result in any prosecution or punishment.

## Soft law rules

Over the past 50 years however, numerous programs and actions have been implemented for the conservation and direct or indirect management of coral reefs. These legal initiatives fall under the definition of soft law. They have been implemented, in terms of binding law, through the following legal mechanisms:

- most often, the legal procedure of protected areas and particularly marine protected areas (MPAs);
- legal rules on protected species and the protection of "marine biodiversity" in general;
- legal rules on fisheries management and the prevention of overfishing;
- rules for the prevention, control and remediation of marine pollution;
- rules for the control of invasive alien species;
- rules for the protection of "common heritage" or "World Heritage";
- rules intended to promote tourism.

Since the Paris Agreement on climate and taking into account the impacts of global warming and ocean acidification, legal measures to combat and mitigate these impacts can also be used to protect corals.

## International soft law texts that can be mobilized

Several soft law texts are applicable in New Caledonia and can be mobilized to protect coral reefs here.

At the international level, France signs and ratifies treaties, agreements and conventions. Not all agreements signed by France are automatically applicable in New Caledonia. The protection of biodiversity was devolved to New Caledonia and its provinces in 1988, and it is therefore necessary to ensure that international agreements are applicable to the area. These protections include the following agreements, which can be used for the conservation and management of coral reefs:

- the MAB program, Biosphere Reserves (UNESCO, 1971);
- the Ramsar Convention on Wetlands (1971);
- the Convention on the Protection of the World Cultural and Natural Heritage (UNESCO, 1972);
- the United Nations Convention on the Law of the Sea (Unclos, 1982);
- the Convention on Biodiversity (1992);
- the International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004);
- Aichi Biodiversity Targets (2010);
- the International Coral Reef Initiative (ICRI). ICRI is defined as "an informal partnership between nations and organizations working to preserve coral reefs and related ecosystems around the world". While the ICRI is an informal group whose decisions are not binding on its members, its actions have been instrumental in continuing to highlight the overall importance of coral reefs and associated ecosystems for environmental sustainability, food security and social and cultural well-being;
- The UN Agenda 2030, particularly Objective 14 and its seven sub-objectives;
- the Paris Agreement on climate (2015).

## National texts favorable to coral reefs

At the national level, considering only the most recent texts, it is also important to mention the n° 2016-1087 Act for the restoration of biodiversity, nature and landscapes. Article 113 of the Act states that "to stop the loss of biodiversity in overseas France and preserve its role in promoting the adaptation of the territories to climate change, the State shall set the following objectives, with the support of its public institutions under its supervision and in consultation with the relevant local authorities":

1. Develop and implement a program of action at the scale of the territory to protect 55,000 hectares of mangroves by 2020;
2. Develop an action plan contributing to the protection of 75% of coral reefs in the French overseas territories by 2021, within the framework of the French coral reefs initiative and on the basis of an assessment of the state of health of coral reefs and associated ecosystems carried out every five years.

While Article 113, which comes under soft law, has not been made directly applicable in New Caledonia, the State may act with New Caledonia and its provinces - through its research establishments, IFRECOR and the French Agency for Biodiversity (AFB). It can also be assumed that funding requested by the New Caledonian authorities from the State for the protection of mangroves and coral reefs in the archipelago will be granted under Article 113.

## Regional agreements that can be implemented in New Caledonia

Environment Program (SPREP) and the Pacific Islands Forum. The agreements and action programs of these regional organizations can be implemented in New Caledonia.

To date, there is no legally binding coral reef legislation at the regional level. In January 2018, on the occasion of the launch of the third IYOR (International Year of the Reefs), from the available solutions, Fiji chose the Ramsar Convention on Wetlands to protect their Great Barrier Reef (Cakaulevu). In this convention, wetlands have a fairly broad definition and can include coral reefs.

Soft law documents have existed for a long time and allow the adoption of action plans for reefs. The first of such documents was the Apia Convention on the Protection of Nature in the South Pacific (1976), which was approved by France in 1988 and has been in force since 1990. It focuses on broad environmental protection with incentives for the creation of conservation areas to protect "representative samples of natural ecosystems".

Following this, in 1986, the Convention for the Protection of Natural Resources and Environment of the South Pacific Region, known as the "SPREP (or Nouméa) Convention", included the South Pacific in the Regional Seas Program of UNEP (United Nations Environment Program), which was itself launched in the early 1970s. Control measures - against pollution sources, in particular - provide actions which support coral reefs, even if they are not mentioned in the Convention.

Interestingly, SPREP declared a double Year of the Reefs (2018-2019) to promote the protection of coral reefs among its member states.

## The legal texts of New Caledonia

In the legal order of New Caledonia, there are several texts pertaining indirectly or directly to the coral reefs of the archipelago.

With respect to the general provisions, reference should be made to the amended Organic New Caledonia Act 99-209, which allocates jurisdiction between the State, New Caledonia and its provinces. The protection of biodiversity falls within the normative jurisdiction of each of the three provinces, hence the existence of three environmental codes that apply within their geographical boundaries. The maritime zone outside one of the provinces but within the limits of the Exclusive Economic Zone (EEZ) falls within the jurisdiction of New Caledonia. Coral reefs located in the public maritime domain of a province fall under provincial jurisdiction and those located in the EEZ currently fall under the protection and management rules adopted by New Caledonia. This means that there may be four different protection regimes in existence (even if there are also informal or formal mechanisms and space for consultation and harmonization, such as the Conservatory of Natural Areas). As well as these different regimes of formal law, endogenous law (customary rules) also plays an important role regarding the management of maritime spaces, as part of customary land tenure, which may involve the inclusion of protected areas under endogenous law. Their effective consideration by the entire population requires a formalization that only the Loyalty Islands Province has formally accepted, initially in the form of the "Ouvéa Joint Declaration" co-signed by the customary and provincial authorities in 2007 and later in its Environmental Code in 2016.

At the level of New Caledonia's maritime zones, the protection of reefs may be carried out within the categories of marine protected areas provided for in the 2011 51/CP decision. In accordance with this decision, the decree of April 23rd 2014 was adopted for the creation of the natural marine park known as the Natural Park of the Coral Sea. However, by early February 2018, no practical rules had yet been adopted for the specific protection of coral reefs. As part of its expertise in foreign trade, New Caledonia also acts for the protection of corals and, since 2009, has imposed a ban on coral exports.

Finally, the jurisdiction (shared with the State) over external relations at the scale of the Pacific region provides the possibility of

signing bilateral and multilateral agreements on the protection of coral reefs. The provinces are involved in the legal protection of coral reefs through the various provisions of their respective environmental codes (protected areas, protected species, actions against pollution, etc.).

Among the measures that specifically target corals and fall under binding law, mention should be made of the provisions of Title III of Book 2 of the South Province Environmental Code, which are dedicated to the conservation of "ecosystems of heritage interest", including coral reefs over 100 $m^2$.

As we can see, it is either rare or impossible to find binding legal texts imposing enforceable rights and obligations specific to coral reefs. This is particularly worrying when we know that protection, especially through the protected areas mechanism, is not always satisfactory (chap. 43), and neither are the actions taken to combat pollution. The 3rd International Year of the Reefs should be used to study the feasibility of an international convention on coral reefs, including necessary regional, national and local variations, with binding provisions to protect them more effectively. The recognition of the legal status of the ocean and elements of marine biodiversity - such as coral reefs, which would thus be granted rights of their own would be a real step forward.

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*Chapter 46*

# New Caledonian reefs and lagoons on the UNESCO World Heritage List

*Myriam Marcon*

N'dué Islet, Southern Lagoon. © P.-A. Pantz

## International recognition as a catalyst for action and cohesion

"The lagoons of New Caledonia: reef diversity and associated ecosystems" joined the prestigious World Heritage List in 2008. Thanks to strong support from the French Coral Reef Initiative (IFRECOR), New Caledonian stakeholders joined forces and submitted a collective application.

Since then, efforts and commitments around the protection of reefs, a major element of the inscribed sites, have multiplied. While there was only one management committee at the time of nomination, there are now 13 management committees looking after the heritage property. Representing the local populations (customary, institutional, economic, tourist, educational, educational and associative sectors, etc.), these committees design and implement management plans for the various sites included in the list, the main purpose of which is to maintain their integrity. Over the past 10 years, ten management plans have been implemented.

## Networking for more efficiency

The CEN (Conservatoire d' espaces naturels), which is responsible for coordinating the management of the New Caledonian World Heritage property, provides a platform of exchange between

Boat Pass, Northern Lagoon © P.-A. Pantz

managers. Since its creation, the CEN has worked towards the production of networking tools: e.g., the management committee forum, training courses and promoting experience sharing. The aim is to strengthen the skills of management committees and increase the effectiveness of their actions.

Various communication and awareness-raising tools developed by the CEN promote the World Heritage Convention and encourage good practice. Examples include "My name is lagoons", a video aimed at raising awareness among tourists, or the exhibition "Les gardiens du trésor" ("Guardians of the treasure"). All tools are made available to the New Caledonian stakeholders involved in managing this heritage.

Inscription on the World Heritage List also allows stakeholders in New Caledonia, to benefit from the experiences of other marine site managers around the world. The conferences organized by the World Heritage Center represent extremely rich opportunities for exchanges, particularly regarding global issues, such as climate change, cruise tourism, etc.

IFRECOR, which has been coordinated locally by the CEN since 2016, is an additional platform for engaging in discussions and actions to protect reefs and associated ecosystems.

## A jewel in the Pacific

Since the World Heritage listing, increased attention is being paid to the lagoons and reefs of New Caledonia. Populations, institutions, associations, and researchers are increasingly aware of the importance of this jewel, which is now recognized worldwide.

# New Caledonia
# World of corals

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Bay of Upi, Isle of Pines. © P.-A. Pantz
Coral biodiversity of Larégnère reef. © IRD/S. Andréfouët

Cover page 4 (from left to right):
Loading of a mïkwaa net on a decked pirogue at Pwadèwia, St. Joseph Bay, Isle of Pines, 2017. © M. Juncker
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