Chapter 16

Functional biodiversity in the lagoon

Laurent Vigliola, Nicolas Guillemot, Laurent Wantiez and Michel Kulbicki

The humphead parrotfish *(Bolbometopon muricatum)* is a good example of species that combine several ecological traits essential to the good functioning of reefs. © National Geographic Society/E. Sala

Each species has its own function

In Nouméa as in Koné, in Moindou or Pouébo, in cities or in tribes, everywhere in New Caledonia as in the rest of the world, human societies function according to the same principle: the farmer plants, the baker makes bread, the bricklayer builds, the teacher teaches, the artist creates... Each person has a function, a more or less important role that contributes to the good functioning of our societies. In the lagoon, as everywhere else in nature, the same principle applies: herbivores graze, carnivores hunt, detritus feeders recycle... Each species has one or more functions which are of variable importance. However, there is a golden rule: the role played by each species is key to the functioning and very existence of ecosystems. For the reef and lagoon to be maintained, it is essential that all functions be performed by one or more species.

Functional diversity is defined as the number of functions or roles played by species within an ecosystem. Assessing functional diversity is a complex process for many reasons. First, each species can perform a multitude of roles, and each role can be of variable importance. A species can be useful to the ecosystem as prey because it feeds its predators. Being prey is therefore one of the functions of this species. This same species also eats and performs several other functions. For example, herbivores control the growth of algae and thus help regulate the competition between algae and corals. The humphead parrotfish is a well-studied example of a species with several essential functions. This species nibbles at corals and algae that cover the reefs, allowing other species to colonize the newly available area which leads, therefore, to a renewal of the local fauna and flora. The small pieces of coral that the fish cannot digest are expelled as a cloud of fine sand, which adds to sedimentary zones that shelter other species. The sediment produced by a single school of these fish can reach several tons per year. Through this example, it is possible to conceptualize the link between the life-history traits of species and their functions in the ecosystem.

Complementary functional entities

Species have a set of life-history traits, not just diet traits, the combination of which is unique to each species. Currently, our level of knowledge is insufficient to define the exact roles of each species. However, by categorizing the traits of each species, it is possible to classify species into groups with similar characteristics, which are assumed to have very close ecological functions. As illustrated in the previous example, diet is an important functional life-history trait. For fish, a distinction is generally made between piscivores, carnivores, herbivores and detritus feeders, omnivores and plankton eaters. Each of these categories can be broken down further. Other life traits commonly used to classify fish into functional groups are the size of species, mobility, their position in the water column, period of activity and gregariousness, to which could also be added traits related to reproduction and behavior. In all of these traits, size plays a key role. In fact, it influences most other traits, particularly in prey-predator relationships, as it determines the energy required for metabolism and thus the amount of food needed for the survival of individuals. Mobility is also a life-history trait linked to energy needs, as mobile species take their resources from a wider territory than sedentary species. In addition, by moving, they transfer energy between the different habitats of an ecosystem. The period of activity also has functional implications because nocturnal and diurnal species are not accessible to the same predators and do not feed on the same prey. The level in the water column is an important functional trait that contributes to energy fluxes between the bottom of the lagoon and the surface, and between open ocean and reefs. Finally, gregariousness is linked to the functional footprint of species, with individuals living in large schools having a massive impact on nutrient transfers within the ecosystem.

Each of these life-history traits can be either quantified (e.g., a species that can reach a maximum size of 48 cm in adulthood) or codified into categories (e.g., a medium-sized species). The combination of these characteristics makes it possible to define more or less complex functional classification schemes. For example, a simple scheme would combine size and diet, with functions (or functional entities) such as "large-sized piscivore","medium-size herbivore" or "small-sized carnivore", and a complex scheme would combine all the available life traits (e.g., "very mobile large-sized solitary nocturnal piscivore hunting in open water"). These classifications allow the estimation of functional diversity, simply by counting the number of existing combinations. These combinations or functional entities are an approximation of the true functional diversity which remains beyond our measurement capabilities.

Numerous studies based on this approach show that, on a reef, the number of functions is less than the number of species. The number of functions increases only very slowly above a certain number of species, as indicated by a study of the Koné lagoon in New Caledonia (Fig. 1). New functions keep emerging when the specific diversity is very high. These functions are represented by few species and, in general, few individuals, making them highly vulnerable, especially since they appear only with exceptional levels of diversity. This is very important because the more functions within an ecosystem, the more productive, stable, resistant and resilient it will be. This is linked to the concept of ecological niches, which states that each species has a specific habitat and role in an ecosystem, but at the same time each new species adds a new resource on which new species can establish themselves. New functions are therefore generated by pre-existing functions in a process of enrichment and optimization of the ecosystem.

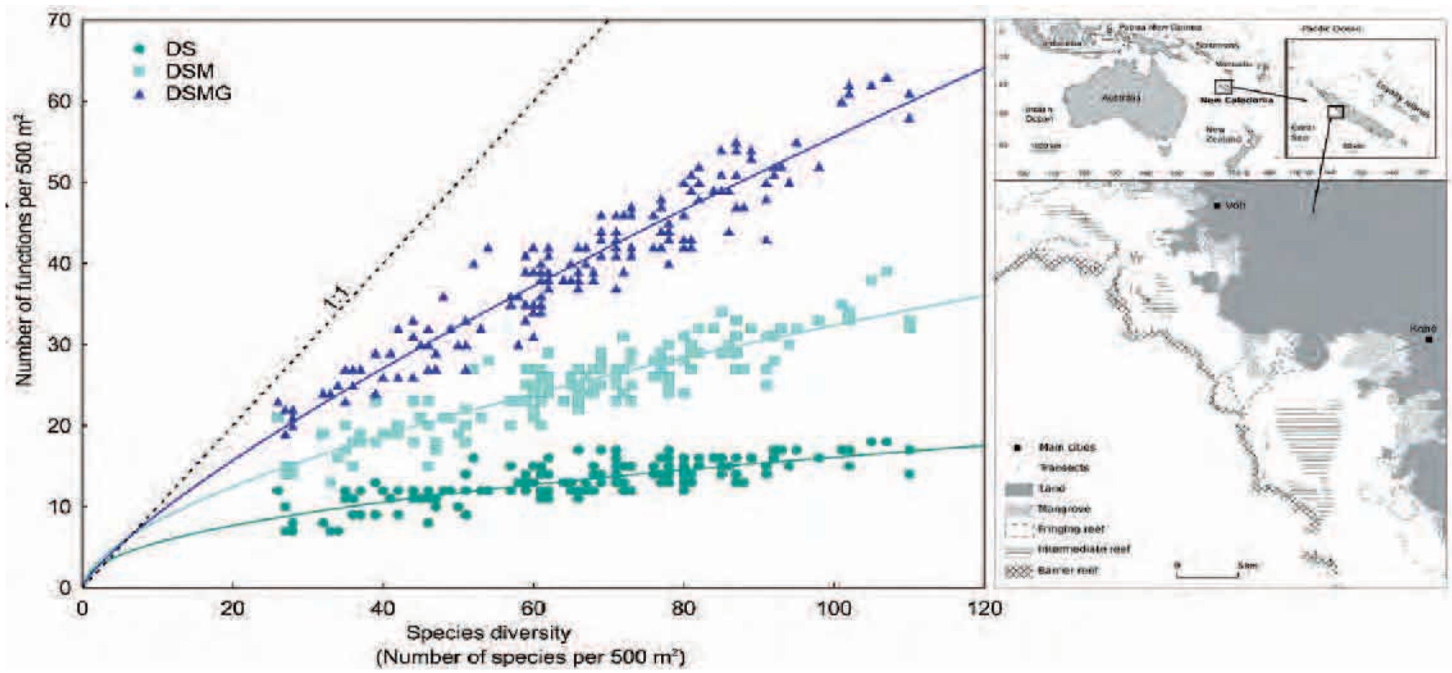

Figure 1: Relationship between specific and functional diversity for Koné coral reef fish species and for different functional classification schemes.
D: Diet. S: Size. M: Mobility. G: Gregariousness. Adapted from GUILLEMOT *et al.*, 2011

Diversity: a factor of resistance to disturbances

As seen earlier, the more species an ecosystem has, the more functions it will have, and the more likely it is to have the necessary function(s) to resist disturbance. In other words, functional diversity provides a sort of insurance for ecosystems. Similarly, when several species have the same function, it protects the ecosystem against the consequences of a local species extinction (following a disease, for example). On a particular reef, many species appear and then disappear with changes in recruitment, habitat or resources. As long as all functions are retained, then the ecosystem can be maintained, regardless of the exact identity of the species that make up the community. Functional redundancy increases the resilience of an ecosystem (i.e., its capacity to last over time), because several species with the same function ("functionally interchangeable species") will have to be impacted before the function is lost. Conversely, poorly-redundant functions are vulnerable, the most vulnerable being functions performed by a single species. When this is the case and the function is essential to ecosystem functioning, it is referred to as a "keystone species" whose presence or absence can influence the whole ecosystem.

There are, therefore, two opposing forces in action. On one hand, having many functions increases the resilience of a system in case of disturbances. On the other hand, functional redundancy makes each function less vulnerable. An increase in the number of species is likely to reinforce the redundancy of existing functions and the appearance of new ones. The Koné study has found these two forces in action. In New Caledonian reefs, the number of functions observed in fish assemblages is lower than expected by chance, given that the number of species present at each site was below a threshold of about 90 species per 500 m^2 (Fig. 2).

Below this threshold, species diversity tends to reinforce functional redundancy, and therefore the ecosystem's resilience to local species loss. Beyond the threshold of 90 species, the number of functions in assemblages does not differ from what can be expected by chance. Therefore, beyond this threshold of 90, the functional diversity tends to increase with the addition of new functions, which are rare and vulnerable but allow for a better partitioning of resources and therefore a more energy efficient system.

The world's last wild reefs

New Caledonia has an EEZ (Exclusive Economic Zone) of 1,740,000 km^2. In this immense maritime domain, some reefs are under strong human influence, particularly those near the capital Nouméa, which attracts two-thirds of the New Caledonian population. Other reefs, such as the Chesterfield Reefs, are extremely isolated in the middle of the Coral Sea, sometimes over 40 hours away from any human population. A recent study compared the functional diversity of coral reef fish along this decreasing gradient of human impact. It shows that the fish functional diversity is maximal on coral reefs located more than 20 hours from Nouméa. The study also revealed that this functional diversity declined by 60% in the inhabited areas of the archipelago (Fig. 3).

This means that the lagoon is seriously short of the work force it needs to function properly, as many functions have been severely affected, particularly by fishing. This functional erosion has serious consequences for the lagoon because a poorly functioning ecosystem degrades quickly. However, solutions do exist. The provinces of New Caledonia have created numerous marine reserves, which are capable of partially restoring functional diversity. More recently, the government of New Caledonia has created the Natural Park of the Coral Sea, which includes most of the isolated reefs of the archipelago. Protecting these reefs is a huge responsibility for New Caledonians, as our latest estimates (MAIRE *et al.*, 2016) indicate that only 1.5% of the coral reefs located over 20 hours away from human populations, are left in the world. New Caledonia has one third of these last functionally intact reefs. To formally protect the planet's last wild reefs unaffected by most human impact, would be a strong symbolic action by New Caledonians in 2018, the year of coral reefs.

References

D'AGATA S. *et al.*, 2016 Marine reserves lag behind wilderness in the conservation of key functional roles. *Nature Communications*. doi : 10.1038/ncomms12000.

GUILLEMOT N. *et al.*, 2011 Functional redundancy patterns reveal non-random assembly rules in a species-rich marine assemblage. *Plos One* 6 (10) : e26735. doi : 10.1371/journal.pone.0026735.

MAIRE E. *et al.*, 2016 How accessible are coral reefs to people? A global assessment based on travel time. *Ecology Letters*. doi : 10.1111/ele.12577.

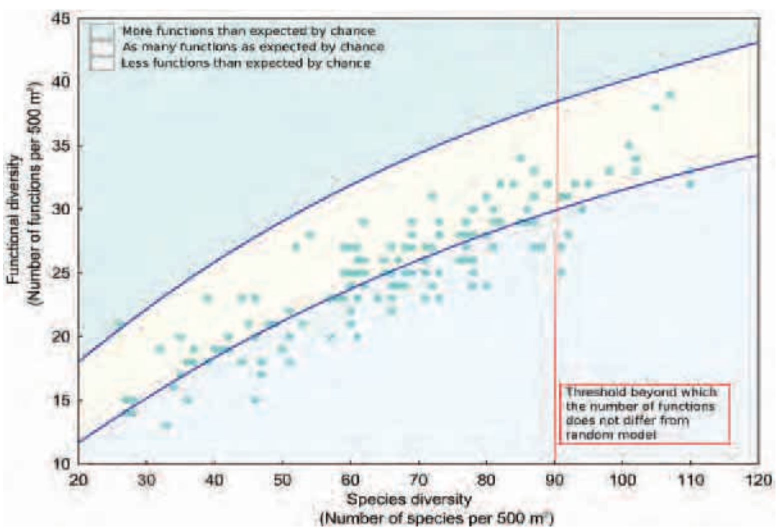

Figure 2: The relationship between the species and functional diversity of coral reef fish in New Caledonia. Adapted from GUILLEMOT *et al.*, 2011

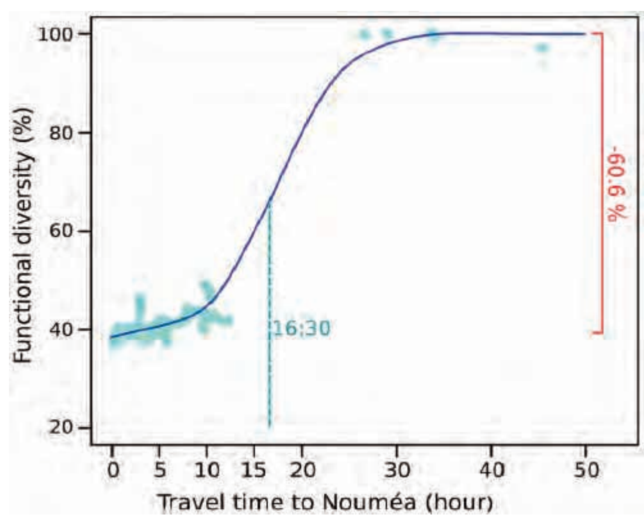

Figure 3: The relationship between the functional diversity (in %) of fish in New Caledonian coral reefs and travel time to Nouméa. Adapted from D'AGATA *et al.*, 2016

School of yellowfin goatfish *Mulloidichthys vanicolensis*. This occasionally gregarious species lives on sandy bottoms in reefs and lagoons. Adults are often solitary and live on sandy slopes where they feed on small invertebrates. © M. Juncker

New Caledonia
World of corals

Scientific direction: Claude E. Payri

IRD Editions
French National Research Institute for Sustainable Development, Marseilles, 2018
Editions Solaris

Translation: Lydiane Mattio
Editorial coordination: Claude E. Payri
Page and cover layout : Pierre-Alain Pantz - Editions Solaris
Printing: Winson Press, Singapour

Cover illustrations

Cover page 1 (from top to bottom):
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
Clown fish eggs. © G. Boussarie
Incubation of coral colonies in benthic chambers. © CNRS/E. Amice
Flying Red-footed booby *(Sula sula)*. © M. Juncker

ISBN : 978-2-7099-2677-5

Recommended citation:
Payri, C.E. (dir.), 2018 – New Caledonia: world of corals. IRD Editions/Solaris, Marseilles/Nouméa, 288 pp.