*Chapter 24*

# Super corals in New Caledonia can resist climate change

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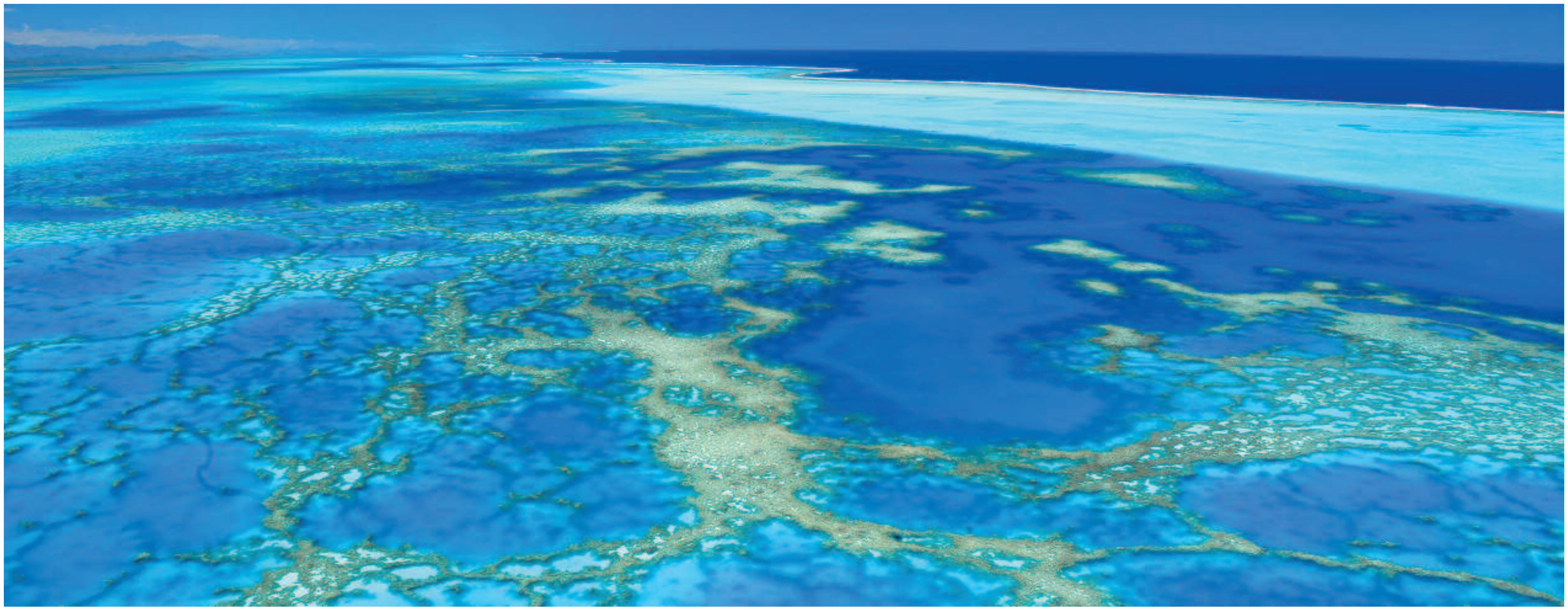

Reticulated lagoon, Nessadiou. © Province Sud/M. Dosdane

## Coral reefs under threat from climate change

Coral reefs are already significantly impacted by climate change (GATTUSO *et al.*, 2015). Since the industrial revolution, atmospheric $CO_2$ levels have almost doubled, leading to global warming and ocean acidification. The effects of climate change on coral reef organisms have been extensively studied in recent decades, and experiments have been mainly conducted in tanks.

Calcifying species, such as reef-building corals, which host a substantial portion of the world's ocean biodiversity, are likely to be among the most affected by ocean acidification. This is because their calcification and dissolution rates appear to be related to the chemistry of carbonates in the oceans (box. 19). Several studies thus show a decline in coral calcification rates and, at the same time, an increase in dissolution rates of carbonate skeletons when the pH of seawater decreases. Ocean warming is also a major threat to marine life, and coral reefs have already been severely affected in recent decades. Sea surface temperatures which rise only 1°C above the maximum summer temperatures for at least two to three days, result in the loss of the coral's symbiotic algae (known as coral bleaching, chap. 25). Several studies indicate that most corals are able to recover from bleaching if temperature anomalies persist for less than a month, but the stress generated by high temperatures can cause permanent damage to coral metabolism.

Massive coral mortality, following bleaching events, was reported worldwide in 1998 and 2016. Although the majority of studies have shown a decrease in coral calcification rates with the reduction of pH in seawater, and massive mortality from bleaching due to higher temperatures, it appears that some corals are capable of acclimatizing to ocean warming and acidification. These divergent results reflect the difficulty of adequately and consistently reproducing complex environmental and ecological interactions in laboratory experiments. The scientific community has made considerable efforts over the past 15-20 years to understand the impact of global change on coral reefs and to more accurately predict how these ecosystems will change in the future. However, most conclusions about the impacts of climate change on corals and extrapolations to the ecosystem level are based on short-term laboratory experiments carried out on isolated individuals exposed to artificial conditions.

These experiments are useful, because they identify the effects of one or more parameters in isolation, but they are unable to take into account the acclimatization (and adaptation) of species in their natural environment. Laboratory experiments are not ecologically realistic because they do not take into account the effects of species interactions, natural food supply, or fluctuations in key environmental parameters. In addition, almost all of these studies have neglected the role of adaptation, as they have only tested responses to global change within the same generation of individuals and during very short periods of stress exposure.

In addition to ocean acidification and warming, the oxygen saturation rate of seawater decreases due to higher temperatures and coastal eutrophication. Little is known about the consequences of this for organisms, but they are likely to be negative. Deoxygenation, together with ocean acidification and warming form a "deadly trio", which could permanently affect the oceans by 2100.

In order to better predict the fate of marine organisms in response to climate change, it is time to scale up and address ecosystem-level effects. This requires finding coral reefs that are already exposed to environmental conditions that have been predicted for the end of this century. One might think that this is impossible, but there are several examples in nature. Some of these places are far from us, in Papua New Guinea, others are much closer and can be found in New Caledonia!

## Studying extreme environments for the prediction of coral reefs' futurees

Populations of corals currently living at the margins of their optimum environment and acclimatizing to extreme environmental conditions have become models for predicting the future structure and functioning of coral reefs. Natural systems such as volcanic $CO_2$ vents (HALL-SPENCER *et al.*, 2008, FABRICIUS *et al.*, 2011) offer unique opportunities to study the future of coral communities exposed to global change. To date, no perfect natural systems have been discovered, but the data from the existing ones are of fundamental ecological relevance for providing realistic and natural scenarios. For example, at $CO_2$ vents in Papua New Guinea, pH varies over time, depending on environmental conditions (e.g., changes in prevailing currents and atmospheric conditions) and its effect is usually limited in space (about 100 square meters of the reef). In addition, at these sites, only the effect of ocean acidification can be observed because only "cold" resurgences of $CO_2$ have been discovered, although it is clear that warming will be the most influential factor in the future. The French National Research Institute for Sustainable Development (IRD) started a long-term research program at three volcanic sites in Papua New Guinea (CARIOCA project). A series of physiological and molecular analyses, coral transplants and multigenerational experiments will provide more reliable predictions on the responses of organisms and ecosystems to ocean acidification.

In February 2016, a collaboration between the IRD and the University of Technology Sydney (Australia) led the first field work at an exceptional site in Bouraké, 150 km from Nouméa (CAMP *et al.*, 2017). At this site, lagoon waters flow into the mangrove with high tide, circulate inside the system and exit at low tide. The depth of the system varies from a few centimeters to more than 6 m. The channel, which is more than 80 m wide, penetrates into the mangrove and creates large pools over a total area of more than 60,000 $m^2$.

The first measurements of the daily pH fluctuations (Fig. 1), during a 24-hour cycle, revealed the value of this unique site for studying the capacity of corals to acclimatize and adapt to extreme conditions. At each high tide, new lagoon water enters through the channel into the vast inner basin of the mangroves. During this journey, the water chemistry changes, due to metabolic reactions in the sediment, coral reefs and mangrove habitats, and it mixes with more acidic, hot and deoxygenated seawater. Even at high tide, the water in the system never returns to "normal" values. For example, the maximum pH values are around 7.9 (the normal pH of the ocean is currently 8.05 and is predicted to decrease to 7.7-7.8 in 2100). At low tide, seawater becomes more acidic and oxygen-depleted as the system begins to drain. The large volumes of water that were inside the mangrove forest enter the system and are then discharged into the lagoon. At low tide, near corals, the pH reaches the extreme value of 7.3 and $O_2$ reaches a concentration of 2 mg $L^{-1}$ (the normal concentration of $O_2$ at the coast is 4-6 mg $L^{-1}$).

All these parameters exhibit clearly detectable fluctuations over a 24-hour cycle, which is extremely important in assessing the amount of stress that corals experience over time. This makes this site much more interesting than other natural laboratories in which the duration and intensity of stress (e.g., volcanic vents) are not consistent in time or space.

According to recent literature on the effects of climate change on coral reefs, the persistence of corals and calcifying organisms in general is likely to be seriously compromised. Yet, the IRD experiments at Bouraké revealed the presence of more than 50 different species of corals, which form very well-preserved reefs similar to other fringing reefs of New Caledonia.

There is no doubt that this site offers new opportunities to better understand the future of coral reefs in response to global change. The main hypothesis, which has yet to be verified, is that many marine species, considered by previous laboratory studies to be sensitive to

Study site at Bouraké showing the main channel through which seawater from the lagoon enters the mangrove. © IRD/J.-M. Boré

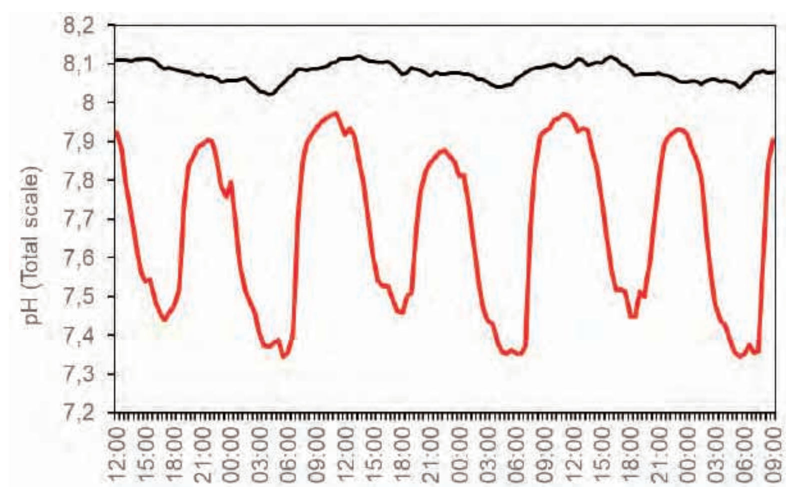


Figure 1: Tidal pH changes at the study site (red) and at a control site, outside the mangrove system (black). © IRD/R. Rodolfo-Metalpa

*Box 19*

## Ocean acidification, a threat to corals?

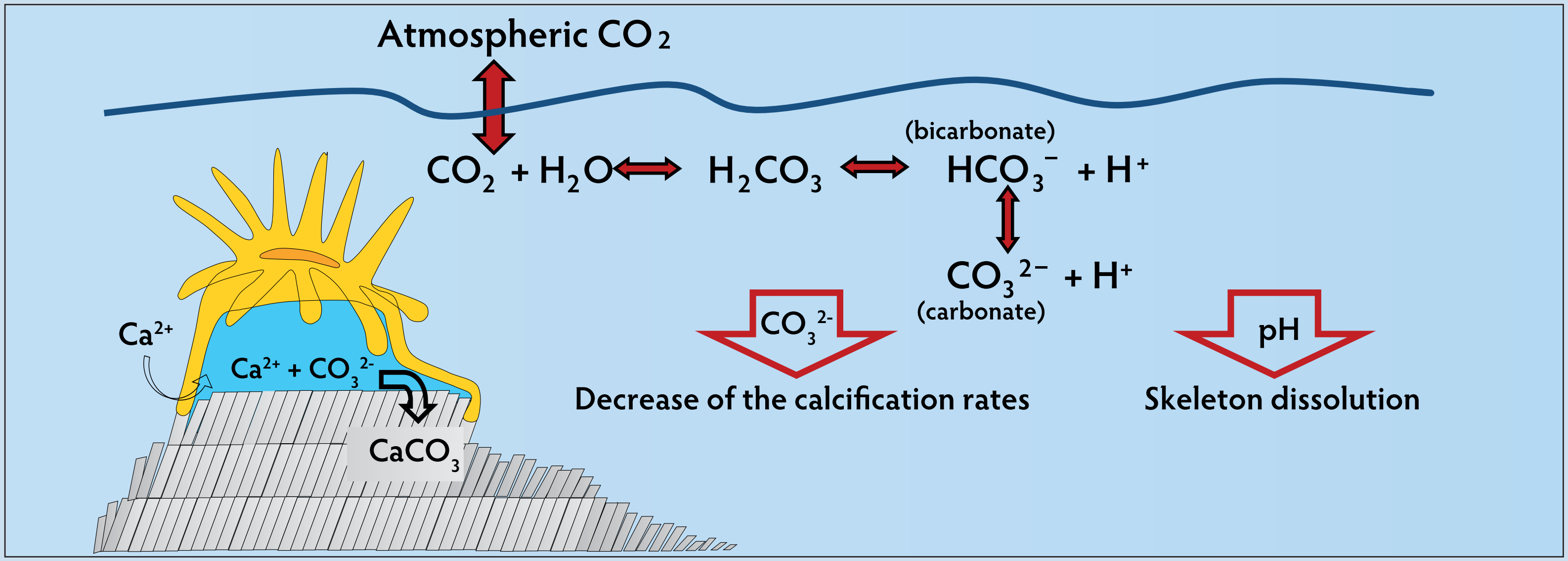


Diagram of calcification and decalcification (dissolution): Dissolved carbon dioxide ($CO_2$) reacts with water ($H_2O$) to produce carbonice acid ($H_2CO_3$): $CO_2 + H_2O \leftrightarrow H_2CO_3$
Carbonic acid is then uncoupled in bicarbonate: $H_2CO_3^- \leftrightarrow HCO_3^- + H$
The bicarbonate ion is also uncoupled in carbonate ion: $HCO_3^- \leftrightarrow CO_3^{2}- + H^+$
In water, the three compounds $CO_2$, $HCO_2^-$, and $CO_3^{2}-$ are in stable proportions depending on pH conditions.

### Will oceans be more acidic in the future?

Ocean acidification is about chemistry. Carbon dioxide ($CO_2$), released into the atmosphere by human activities, contributes to global warming (greenhouse effect). About 25% of this carbon dioxide is absorbed by the oceans. Oceans thus contribute in the reduction of the greenhouse effect. In return, this gas increases the acidity of oceans. In fact, the dissolution of $CO_2$ in seawater causes an increase in its acidity, which corresponds to a decrease in pH. This leads to a decrease in the amount of carbonate ions ($CO_3^-$), which are one of the necessary elements for some marine organisms to build their skeletons, shells and other calcareous structures.

### What will be the impacts on the coral ecosystem?

With more acidic waters, animals with calcareous skeletons or shells such as corals will experience difficulties in producing calcified structures because the carbonate ions they use will be less abundant. Organisms will need more energy to calcify, and their skeletons and shells will be more fragile. Responses differ depending on species and some seem to be more resistant to a decrease in pH. Responses also vary depending on life history stages, physiology and the capacity of species to regulate pH at the cell level. Ocean acidification can also facilitate the dissolution of reefs and make them more vulnerable to storms and tropical cyclones.

Aerial view of the Bouraké fringing reef. © IRD/J.-M. Boré

ocean acidification and warming, are in fact capable of acclimatizing to, or even adapting to, future climatic conditions. The main support for this hypothesis is the presence of many coral species in this mangrove system, where pH, temperature and $pO_2$ conditions are close to (or above) the values predicted for the end of the century.

Our aim is to acquire a better understanding of the physiological changes that corals use to adapt to extreme conditions (phenotypic elasticity), which is already an innovative approach. Our ambition is to assess whether these species, which have grown in these extreme conditions, can reproduce and how they potentially have adapted to future-like conditions (for example with transgenerational acclimatization).

Current research aims at investigating i) how changes in metabolism and zooxanthellae allow corals to thrive in extreme environments? and ii) what is the role of microbes and photosynthetic algae (i.e., *Symbiodinium*) living in symbiosis with the corals in the resistance capacity of corals to extreme conditions?

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