Chapter 23

Metals and their impact on corals

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Soils exposed by mining in the north of Grande Terre (New Caledonia). © Koniambo Nickel SAS/ A. Wright

Pollution by metals, a global problem

Coral reefs have significantly declined globally over the last decade as a result of anthropogenic activities (HUGHES *et al.*, 2003). They face many threats including disease, overfishing, habitat destruction and water quality degradation. This water quality degradation is due to several factors: deforestation and mining operations, which increase soil erosion; agricultural and domestic pollution; and dredging operations, which develop along the coast. Metal inputs are also a form of pollution. They are released through soil leaching, industrial effluents, in the form of atmospheric particles and also mainly from mining. Car emissions, sewage sludge, dredged material and antifouling paints also contribute significant quantities of metals to the oceans. This pollution by metals affects many reefs around the world. (e.g., Costa Rica, Panama, the Red Sea, Thailand, Tuvalu, Puerto Rico). Among them, the reefs of New Caledonia are particularly exposed. New Caledonia is one of the five major nickel producers in the world and its open-pit mines require extensive excavations which considerably expose the soil to water and wind erosion. This increases the contribution of metal-rich particles to the lagoon via sediment-rich runoff or atmospheric pollution, threatening the functioning of reefs and their biodiversity.

When there are too many metals in seawater...

The effects of high sedimentation on corals are now well known. High sedimentation decreases the amount of light available for *Symbiodinium* to photosynthesize and generally results in lower growth rates. In extreme situations, high sedimentation can even cause the bleaching of colonies and lead to their partial or total death (FABRICIUS, 2005).

The effects of dissolved metals associated with these high sediment loads are much less studied. It is known that corals have an exceptional capacity to bioaccumulate metals in both their tissue and skeleton. However, experimental studies on the effects of metals on corals have only focused on their reproduction and early life stages. These studies demonstrated that high metal intake resulted in: lower reproductive success; lower larval fixation and survival rates (REICHELT-BRUSHETT and HARRISON, 2005); a change in photosynthesis rates leading to a reduction in the calcification and growth of corals during their early life stages; a loss of *Symbiodinium* in coral tissues and eventually an increase in coral mortality. However, it is very important to note that all these experimental studies used exceptionally high levels of metals: 100 or 1,000 times higher than *in situ* concentrations.

Incubation of coral colonies in benthic chambers to test (directly on the reef) the effect of nickel or cobalt on coral calcification and photosynthesis. © CNRS/E. Amice

What about the corals of the New Caledonian lagoon?

In New Caledonia, additional studies have been carried out to understand the effects of the regular exposure of near-shore reefs to pollution by metals. A series of field and laboratory experiments revealed the effects on coral metabolism of concentrations "characteristic" of those measured in the lagoon. The effects of two metals were tested: nickel and cobalt, which are particularly abundant in coastal waters because of mining activities.

For nickel, concentrations in seawater are generally around 0.1 to 0.5 µg L^{-1}, but concentrations exceeding 20 µg L^{-1} can be measured in some areas along New Caledonia's coastline. Surprisingly, coral colonies exposed to moderate concentrations of nickel (3.5 µg L^{-1}) were not negatively affected, but instead their metabolism was stimulated with increased calcification (BISCÉRÉ *et al.*, 2017). This is the first time that a beneficial effect of nickel on corals has been recorded. One possible hypothesis that may explain the positive role of nickel is related to the activity of urease, an enzyme whose active site contains nickel (Fig. 1).

This enzyme is responsible for the transformation of urea into ammonia and carbon, two elements that are then used in the process of coral calcification. A temporary exposure to a moderate amount of nickel would have stimulated the activity of this enzyme, boosted carbon dioxide production and then increased coral calcification.

In the case of cobalt however, with a minor increase (around 0.2 µg L^{-1}, which is in the range of maximum concentrations found along New Caledonia's coastline), the growth rates of the two species of coral tested dropped by one third and even by 70% when cobalt levels reached 1 µg L^{-1} (BISCÉRÉ *et al.*, 2015).

Metals and corals, friends or enemies in a changing climate?

In addition to local stresses, the coral reefs will now have to cope with global climate change. Climate models forecast an atmospheric warming of 2 to 4°C over the next 30 years (IPCC, 2014). This warming has already triggered massive bleaching events (i.e., when coral tissues lose their symbiotic algae, see chap. 25) in all the world's reefs over the past 30 years. The simultaneous increase in CO_2 concentration (pCO_2) in the oceans also alters the chemistry of water by lowering pH (by 0.1 pH units in the 20th century) and carbonate concentrations (IPCC, 2014).

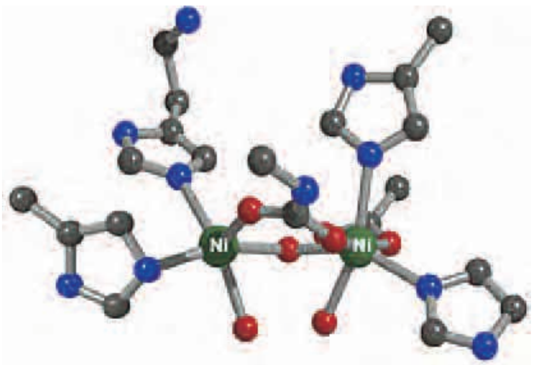


Figure 1: Chemical representation of urease showing the active site containing a double nickel nucleus. Adapted from www.rcsb.org

The scientific community expects that coral reef calcification rates will have decreased by between 17% and 37% by the end of the century. To date, the impacts of climate change on corals have been investigated in isolation (only an increase in CO_2 and/or temperature), assuming that the corals were located in areas free from anthropogenic pollution. Unfortunately, this assumption falls far short of reality, and it is essential to study the synergy between the multiple factors and their cascading effects in order to identify and prevent future threats to coral reefs.

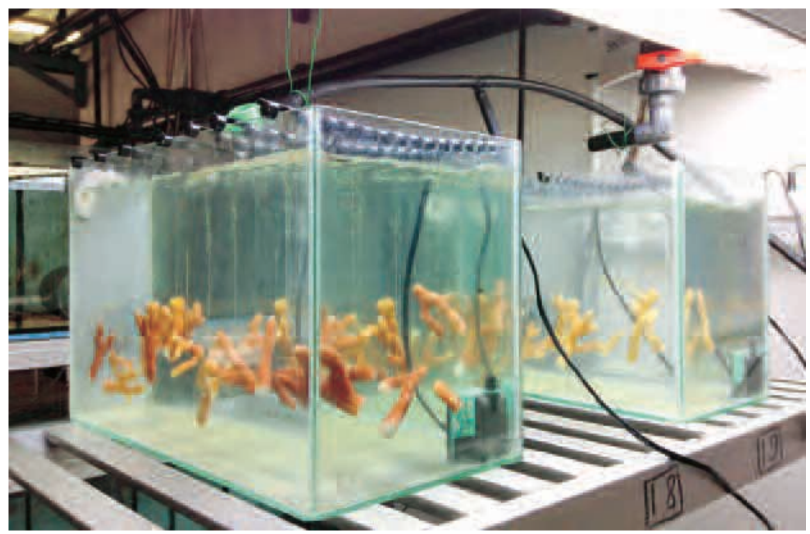
Nowadays, it is difficult to know whether regular inputs of metals, as is the case in New Caledonia with mining operations, will exacerbate the adverse effects of climate change on corals or not. To answer this question, laboratory experiments were carried out to test the combined effects of acidification and warming on several coral species, previously exposed to higher levels of cobalt and nickel.

Results indicated that, even if at "normal" temperatures, nickel stimulates coral calcification, when temperatures increase, nickel amplifies the negative effects of water warming and reduces coral growth by up to 37%. In contrast, colonies incubated for one month at higher pCO_2 (lower pH) and higher cobalt concentrations were less sensitive to acidification and were able to maintain calcification at levels equivalent to controls (maintained at normal pH and cobalt concentrations).

Complex responses to multiple stresses

These studies highlight the complexity of coral responses to multiple stresses. Although under "normal" temperatures a few metals may be useful to specific physiological mechanisms, these effects are offset or even reversed when corals are exposed to an increase in ocean temperatures such as those predicted for the end of the century.

These works only focused on the two most common metals found in the New Caledonian lagoon, but several other metals are being discharged in the lagoon from mining operations and runoff. Furthermore, very little data is available on interactions between metal. A combination of metals can increase or decrease their toxicity or bioavailability to corals. Corals, for which growth rates already declined by 37% when exposed to chronic and moderate nickel supply and temperature stress, will also likely be further compromised when exposed to other threats such as other types of pollution or ocean acidification.



Coral colonies exposed to different cobalt concentrations and temperatures in the laboratories of the *Aquarium des lagons* in Nouméa. © IRD/V. Meunier

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Soil erosion brings metal-rich sediments to the lagoon. © P.-A. Pantz

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