Reef grief

As the first of the world's ecosystems faces extermination at our hands, coral reef ecologist Peter Sale — Assistant Director of the Institute of Water, Environment and Health at the United Nations University in Ontario, Canada, and author of *Our Dying Planet* (published this autumn) — talks to *Nature Climate Change*.

Have coral reefs ever totally disappeared in the two billion years since they evolved?

In each of the five previous mass extinctions, the coral reefs have disappeared all over the world for a very lengthy period of time — tens of millions of years.

When the climate changed again, how did the reefs come back?

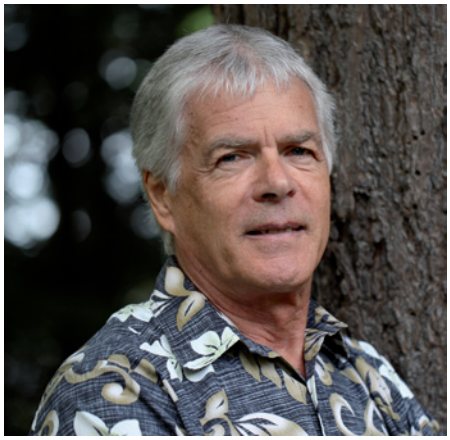
On each occasion there was a small number of coral species that survived in refugia. They were relic species tucked away somewhere, and they were insignificant in terms of their impact on the environment. When the conditions improved, there was an opportunity for speciation. So, for example, the dominant coral reef species we have now — the scleractinian or 'stony' corals — appeared around 65 million years ago, but are derived from earlier corals around that evolved more than 200 million years ago.

What do corals require to develop a reef?

To build a reef, you've got to have an environment where the conditions are favourable for the broad range of calcifying organisms, particularly corals, to prosper and grow, building their carbonate skeletons. These conditions are limited by temperature, and water acidity, clarity and quality. Reefs are always a balance between the forces that allow them to build up through calcification and the processes that break them down, such as physical erosion, bio-erosion (by creatures that burrow through it or scrape it off) and bleaching events.

How are our carbon emissions impacting reefs?

Corals live very close to their upper thermal limits and the first observable impacts on reefs are from rising sea temperatures [from the greenhouse-gas effect]. Corals are unable to cope with the temperatures, they evict their symbiotic algae, which provide their colour (bleaching), and then if they are kept at elevated temperatures for two to three weeks, they start to die. So when the warmer average temperatures coincide with a stronger El Niño, producing extra warmth, you get mass coral bleaching



and mass mortality. What's left behind — remnants of corals in shady places or slightly deeper — are then able to start growing again, given time. But these warm periods are becoming more frequent.

The other impact our emissions are having is through ocean acidification, which may prove to be more important than warming. Carbon dioxide dissolves in the oceans producing carbonic acid, pushing the ocean pH down, which makes the chemical process of calcification much more difficult energetically. So those organisms that depend on calcification to produce their skeletons — corals and a whole range of other things — calcify less rapidly. Corals build weaker skeletons and grow more slowly, and as a consequence, their ability to recover from damage is reduced.

With global warming, ocean acidification, pollution, overfishing and other anthropogenic damage, what's the prognosis for reefs?

This is the first ecosystem threatened with extermination on our planet. I think that by 2050 coral reefs will not resemble anything like what people were used to in the 1960s, 70s and 80s. And that is a very short time frame. When my granddaughter is 40 years old we won't have the coral reefs we have now. We'll still have corals, we'll still have things we'll call 'reefs', but they will be massive limestone structures that were built in the past, with little patches of living coral struggling to survive on them, and they will be getting smaller and smaller over the years. Perhaps, by 2100 there will be nothing resembling the biotically rich, topographically complicated, complex structures we now call reefs.

How does that make you feel, as a reef researcher?

It's strange to be talking about the ecosystem that I've spent most of my life investigating as being likely to disappear from the face of the Earth. We're talking here about eliminating an ecosystem — killing off a whole integrated community of organisms — that has been with us throughout our existence and long before there were people of any type on Earth. And having it disappear from the universe because of our activities — because we have changed the planet and made it a place that reef communities cannot live on — is, I think, a profound impact to contemplate. We've never done it before. Is this right? Is it moral? Does it matter? The world will go on, but it is going to be very much inferior to what we have now.

How will the loss of reefs affect other marine life?

A quarter of the organisms that live in the oceans live on coral reefs. Some can survive in other coastal habitats, but without reefs, a large percentage of these are going to disappear because they are intimately associated with the other organisms of the reef and they can't survive without them. There's a whole suite of fish that can only live in branching corals, for example. The reefs are a hugely productive ecological system in the tropical oceans, which are predominately a nutrient-limited desert. Coral reefs are amazingly good at capturing and sequestering nutrients, developing a huge biomass of organisms functioning as an ecosystem that otherwise wouldn't exist.

My suspicion is that coastal fish populations will be less abundant. But we haven't studied a world where the reefs have disappeared, so it's hard to know.

Will people notice the loss?

Coral reefs make an enormous contribution to the economy of many tropical countries, through fisheries, tourism and other services. Over 50% of the gross domestic product of many Caribbean nations comes from coastal activities delivered by reefs. The

white sandy beaches in front of the hotels are created by reefs, for example, so lose the reef and you lose the whole reason for going there for those tourists who go on tropical vacation simply to lie in the sand — and the whole economy of that country declines as a result. The economy of many of these small countries literally depends on the kind of coastal environment they currently have, which includes an abundance of reefs.

Reefs provide tremendous protection of coast, which is even more important in a time when tropical storms are predicted to become more severe. Reefs naturally grow upwards, so as sea-levels rise, the reefs will grow up with it, and the presence of that rocky rampart offshore provides major shoreline protection against coastal damage from wave action and storms.

Reefs are also very productive both as a generator of income and simply to feed people. They are often the major fishing ground for most coastal populations in the tropics. Around 16% of our protein comes from the ocean, and in developing countries, poor people fish to feed their families and sell a little bit of extra — that's how they survive.

Will reef loss affect any economies in the rich world?

The live-fish restaurant trade, which began in Hong Kong and spread to Los Angeles and beyond, is a multimillion-dollar industry that depends entirely on coral reefs. It has raped reefs across the Pacific and Indian oceans because it has been so badly managed. The reef fish species on the IUCN Red List [of endangered species] are there as a result of the live-fish restaurant trade, or, in one case, because of the aquarium industry. The aquarium industry is also a multimillion-dollar industry, in which the great majority of marine aquarium trade is of animals caught in the wild, mostly reef fish. Tiny butterfly fish are worth $25 each — equate that to dollars per kilo and it becomes pretty profitable.

How can we save the reefs?

First of all, we should value reefs — put a price on them. When communities understand the value of something, they start taking care of it. When people impact the environment in a deleterious way they should pay for the loss of its value. And we need to start caring for local reefs — protecting them not just on paper, but actively managing fishing and pollution or other impacts. Proper protection vastly improves the quality of reefs, and healthy reefs better withstand the deterioration being forced on them by climate change.

And, we have to face up to the fact that we can't keep changing the atmosphere by pumping greenhouse gases into it with impunity. The atmospheric carbon dioxide concentration at beginning of Industrial Revolution was 280 ppm; it was 375 ppm when I co-authored a paper in 2007 warning about the demise of coral reefs (Fig. 1); it's now 390.2 ppm — and it is having immense impacts on coral reefs and on lots of other things in our world. I'd love to see our carbon dioxide levels back to 350 ppm, like in 1985, when coral reefs were flourishing. But the discussions in climate talks at the moment are about 500 ppm and 550 ppm — and that's a death knell for coral reefs.

Should we be using more technological reef restoration methods?

If we corrected the error [by reducing our emissions], we wouldn't need the technological fix to make our impacts more tolerable. Electrical reef regeneration is a just get-rich-quick scheme for the people who peddle this kind of snake oil. There are ways of propagating corals for replenishing reefs, but they are labour intensive and only feasible for very small areas, because you need to get the broodstock and have the culturing facilities to grow the baby corals. Reef restoration can be a viable option in certain circumstances, particularly when there's been some local damage to a place that's economically important, such as a ship grounding or an oil spill. I think it's overrated because natural regeneration can often do the job. And it doesn't work if you haven't removed the cause of the damage — if you have a reef that's chronically polluted, then you're simply killing off new corals by putting them there.

Do you worry that you might be of the last generation to have dived in pristine reefs?

I do worry, yes. I have told my graduate students: don't pitch yourself as a coral reef scientist but as some other kind of scientist who happens to work on reefs, because coral reefs may not be there to research in the future or there may simply not be enough of them. There are people of my generation who have gone back to places they knew as graduate students and they are amazed at how much they've changed in a single working lifetime. Going through the Caribbean, there are some very disappointing sites.

INTERVIEW BY GAIA VINCE

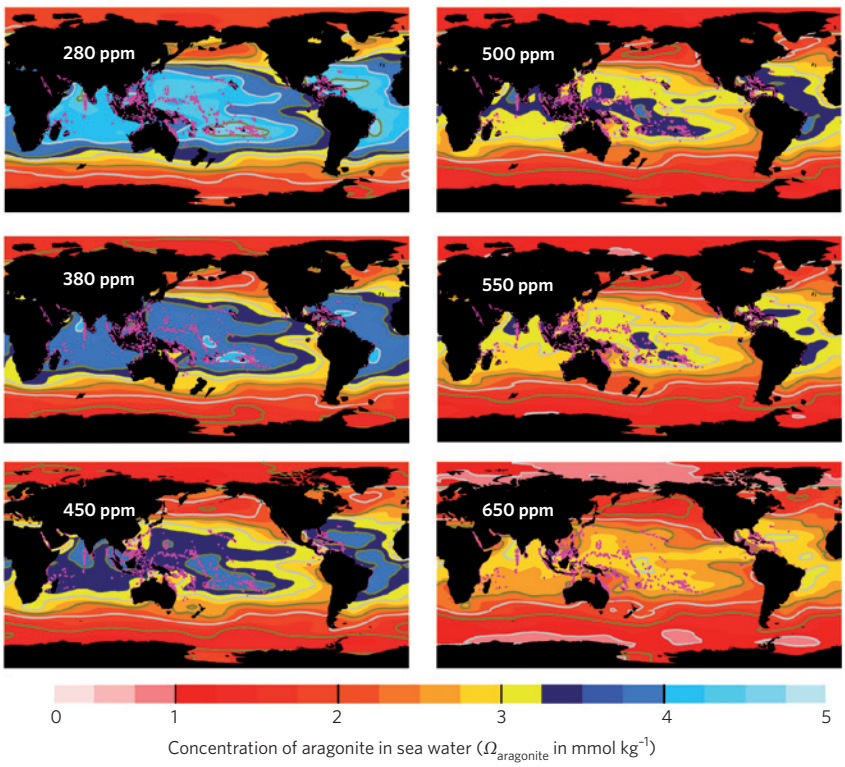


Figure 1 | Changes in aragonite (calcium carbonate in corals and seashells) saturation ($\Omega_{aragonite}$) predicted to occur as atmospheric carbon dioxide concentrations (shown in ppm) increase plotted over shallow-water coral-reef locations (shown as pink dots). Before the Industrial Revolution (280 ppm), nearly all shallow-water reefs had $\Omega_{aragonite}$ >3.25 mmol kg^{-1}, which is the minimum required for a coral reef. Reefs are likely to contract rapidly at carbon dioxide concentrations >500 ppm. Figure from O. Hoegh-Guldberg *et al. Science* **318,** 1737–1742 (2007); reproduced with permission, © 2007 AAAS.