# Drivers of the development of skeletons in corals

**Dr Catherine McFadden** is a Professor of Biology at Harvey Mudd College in Claremont, CA. Her research focuses on the phylogeny and evolution of Anthozoa, an important class of animals that includes corals and anemones. Her current work seeks to understand the effect of increasing atmospheric carbon dioxide on corals' ability to form calcium carbonate skeletons.

Anthozoan cnidarians, a group of animals that includes corals and sea anemones, are some of the most important marine species on this planet. Many species of coral are characterised by their calcium carbonate ($CaCO_3$) skeletal structures, which are precipitated by the animals themselves. Over time, these can develop into large biogenic structures, coral reefs, capable of supporting entire communities of other organisms, in addition to the coral colonies that initially created the reef.

Not all species of coral are colonial or create such skeletons but the ability of reef-building corals to create and provide a habitat for thousands of diverse marine species, supporting both marine ecosystems and human activities alike, makes these species particularly important. However, they currently face many threats from global warming and climate change. The increase of carbon dioxide ($CO_2$) in the atmosphere has caused ocean waters to become more acidic. This is because the seawater takes up more carbon dioxide from the atmosphere, which, in turn, has reduced the amount of carbonate ions in the ocean. Lower availability of carbonate has made it more difficult for calcifying corals to create $CaCO_3$, thus impeding their ability to create skeletal structures.

Similar climatic conditions to those we currently face (i.e., increased atmospheric $CO_2$, increased temperatures and more acidic oceans) have occurred in the Earth's history. However, some fossil evidence suggests that certain corals existed prior to the occurrence of such events and survived them. Understanding this and the evolution of $CaCO_3$-producing anthozoans could provide us with insight into how current coral groups might respond to such environmental changes. Dr McFadden's research focuses on understanding how Earth's past climate has influenced the evolution of skeletons in corals and how this is likely to influence corals in the future.

### THE IMPORTANCE OF CORALS

Corals play a wide role in marine ecosystems. Those that build reefs are currently the focus of many studies, due to their important roles in generating the structure of coral reefs – among the most diverse ecosystems on the planet. Any changes in the environment that affect reef-building species have significant impacts on reef biodiversity – coral reefs sustain a

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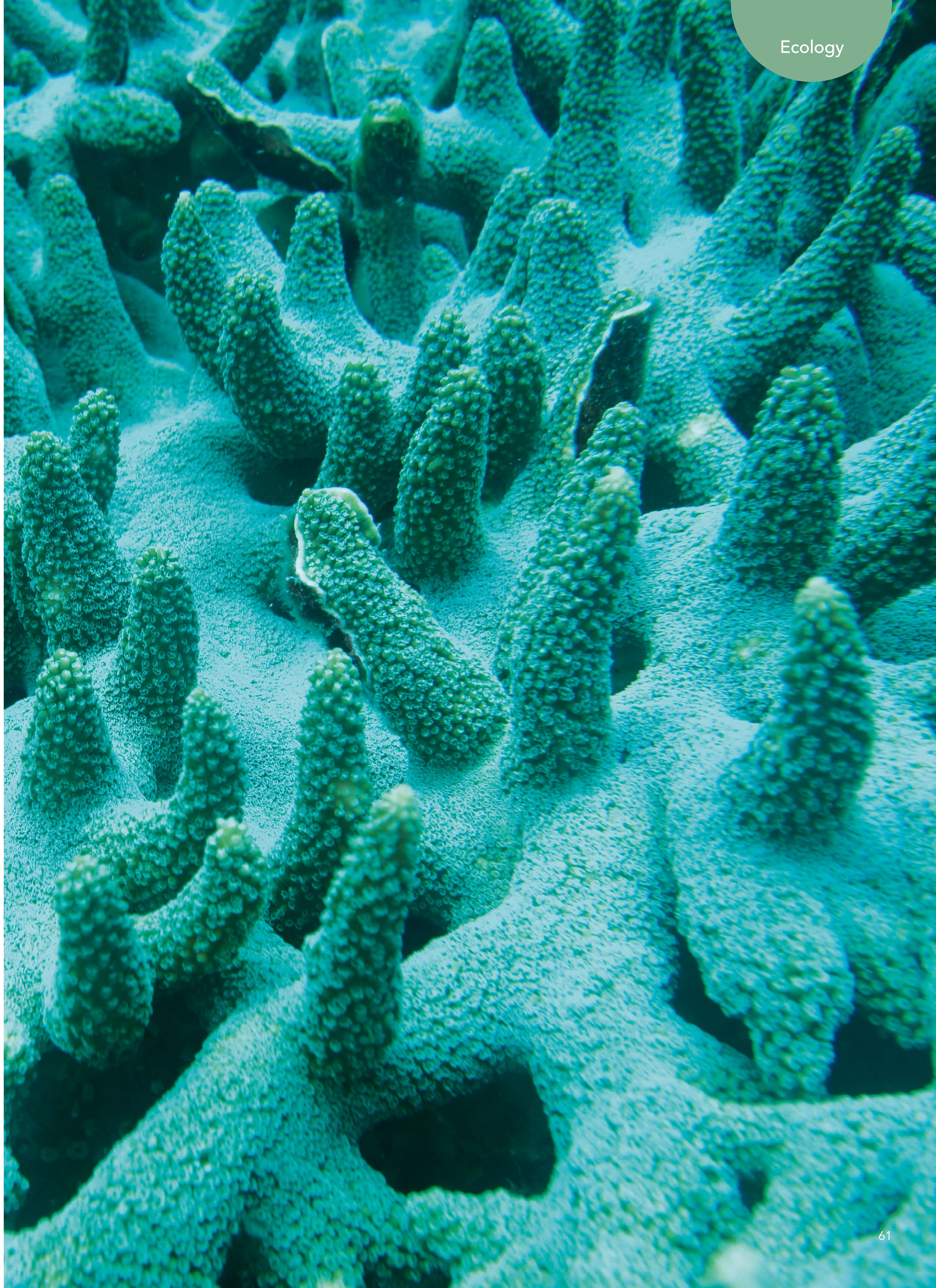


wide range of animals which, in turn, support a wide range of resources and ecosystem services – including fish stocks, nutrient cycling and sediment stabilisation.

Reef-building corals are not the only corals that are vital to marine systems though. There are other species of coral that also produce skeletons in the form of rigid axes made of either $CaCO_3$ or protein, or that simply embed $CaCO_3$ crystals in their soft tissues. While these species do not create reefs, they provide habitat and shelter to animals not only in shallow waters, but also in deep waters, where most typical reef-building corals that require high light levels cannot thrive.

Coral species create a wide variety of skeletal structures that take many forms – all of which are affected differently by environmental change. As coral classification is often based on the structure and formation of their skeleton (or lack of one), by studying the evolutionary lineages of groups of corals, we can understand how different morphologies have been affected by past climate changes and how they are likely to respond to future climate changes, thus identifying which species or groups require more focus for protection.

To study these evolutionary lineages, Dr McFadden and her collaborators, Dr Andrea Quattrini and Dr Estefania Rodriguez, will be studying anthozoan genomes to identify and understand phylogenetic relationships within the class. This will allow them to understand how skeletons evolved and were lost in the Anthozoa, whether the ancestral Anthozoa had skeletal structures, and whether diversification rates within the Anthozoa were responses to past climatic variables. This will also allow them to predict how corals are likely to respond to the predicted climatic and oceanic conditions of the future.

Deep-sea octocorals provide habitat for shrimp and other animals



## PAST CLIMATES

There are three prominent types of skeletons produced by anthozoans – aragonite-based, calcite-based and protein-based, which are observed in black corals and some octocorals. Aragonite and calcite are the most common, and are different forms of crystallised $CaCO_3$, which are most susceptible to changes in ocean acidity. There are also corals that produce no skeleton, which could have evolved because of skeleton loss under low-pH / elevated-atmospheric-carbon conditions of the past (known as the "naked coral hypothesis").

Past fluctuations in oceanic chemistry led to more favourable conditions for the development of calcite or aragonite skeletons, which are referred to as "calcite" or "aragonite" seas (dependent on sea temperatures and the levels of magnesium in the calcite). High levels of magnesium and lower sea temperature are more favourable for aragonite production and low levels and higher temperatures are more favourable for calcite. Shifts in this chemistry could have caused the emergence of scleractinian, reef-building species, while different changes could have also caused mass extinctions of these corals. Similar events could have promoted the emergence of anthozoan species that lack a calcified skeletal structure. By examining the evolutionary lineages of certain groups of Anthozoa, the points at which such diversifications occurred can be identified and related to the climatic conditions at those points in time.

> **By examining the evolutionary lineages of certain groups of Anthozoa, the points at which skeletal diversification occurred can be identified** ”

## THE FUTURE

We are currently facing rapid increases in temperature and atmospheric $CO_2$, with far-ranging impacts for corals and reef health. Changes in coral and reef health affect biodiversity and key marine ecosystem processes, and could lead to the loss of certain coral species and the entire ecosystems they support. On the other hand, changes in climate conditions could also lead to increases and further diversification of corals with different types of skeletons.

It is, therefore, important to understand how anthozoans responded to such conditions in the past to understand how they will respond to future conditions. This will allow us to identify which groups are most at risk, therefore focusing conservation efforts on the anthozoans that most need them.



# Q&A

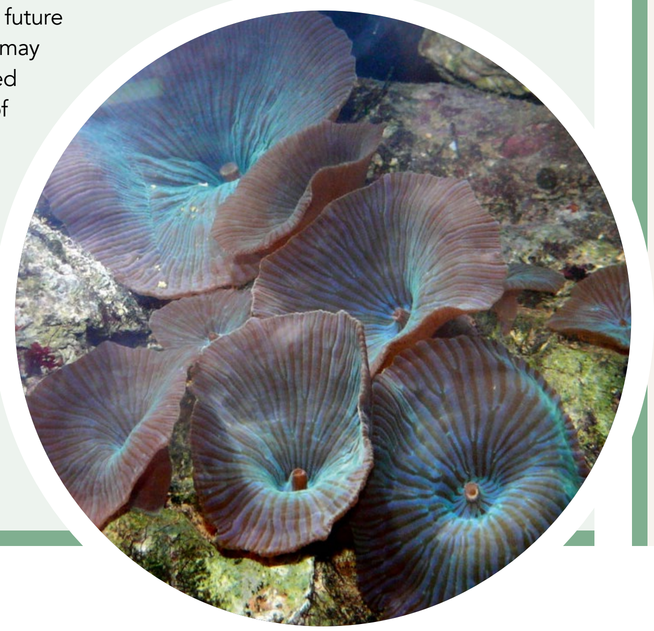
***What services do corals that lack a skeleton provide in marine ecosystems?***
"Soft corals" and sea anemones that lack skeletons often occupy more than half of the space on shallow-water coral reefs. Although they contribute less to building the physical structure of the reef than those species with $CaCO_3$ skeletons, they nonetheless provide food and shelter to many other species. Lacking a hard skeleton for defence, many soft corals instead produce toxic or noxious chemicals to deter predators. Some of these chemicals have been shown to have potent anti-microbial or anti-cancer properties and are now being used for pharmaceutical purposes.

***How likely do you think it is that the "naked coral" hypothesis is true?***
The "naked coral" hypothesis proposes that a group of coral-like sea anemones called corallimorpharians evolved from corals whose skeletons dissolved under past acidic ocean conditions. Recent evidence from studies of their genomes does not appear to support this hypothesis, instead suggesting that corallimorpharians evolved separately from the reef-building corals.

***What implications do you hope your research will have for the future health of corals?***
By better understanding when and under what conditions corals with different skeletal types evolved and the types of environmental changes they have survived in the past, we hope to better predict which species are more or less likely to adapt to and withstand projected future climate change. Such knowledge may help us prioritise which coral-based ecosystems should be the focus of efforts to mitigate the impacts of climate change through stronger environmental protections.

***Do you believe that, as sea temperatures and atmospheric $CO_2$ levels rise, we will see an increase of anthozoans that lack a skeleton?***
What we are more likely to see in the near future is an increase on reefs of anthozoans with different types of skeletons – for instance, certain types of calcite are more resistant to acidification than aragonite. In the Caribbean, we are currently seeing a decrease in reef-building corals with aragonite skeletons, but an increase in octocorals (sea fans) whose skeletons are composed of calcite and protein. Which environmental factors are driving these changes are, however, not yet well understood.

***Which species do you believe are most susceptible to climate change and ocean acidification?***
Based on the carbonate chemistry alone, species with aragonite skeletons (most reef-building corals) are predicted to be more vulnerable than those with calcite skeletons (most octocorals). But laboratory experiments have been showing that some species are very good at buffering their internal environment from pH change, and thereby protecting their skeletons from the effects of acidification. We also know that many corals with $CaCO_3$ skeletons have survived periods of much lower ocean pH in the past. What we don't yet know is how rapidly corals can adapt to changing pH, and if current climate change is too rapid to allow such adaptation.



Corallimorpharia on the sea floor – these anemones are very similar to corals but it is believed that they evolved separately. Image by Haplochromis CC BY-SA 3.0

# Detail

**RESEARCH OBJECTIVES**
Dr McFadden's research focuses on investigating the origins of the cnidarian class Anthozoa, especially octocorals. Her current work seeks to understand the effects of increasing atmospheric carbon dioxide on corals' ability to form calcium carbonate skeletons.

**FUNDING**
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**COLLABORATORS**
- Dr Andrea Quattrini, Harvey Mudd College
- Dr Estefania Rodriguez and Dr Mercer Brugler, American Museum of Natural History
- Dr Brant Faircloth, University of Louisiana

**BIO**
Catherine S McFadden received a BS in Biology from Yale University and a PhD in Zoology from the University of Washington, followed by post-doctoral positions at UC Davis and the University of Liverpool's Port Erin Marine Laboratory. She has been a faculty member at Harvey Mudd College since 1991, where she is currently the Vivian and D. Kenneth Baker Professor of Biology.

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