Bleached reef, Heron Island, GBR, Australia, 2016.

Left: © globalcoralbleaching.org Right: Jack Koch

Innate immunity in coral symbiosis

Dr Virginia M Weis is a Professor and the Head of the Department of Integrative Biology at Oregon State University, with an extensive background in researching dinoflagellate symbiosis with marine animals such as corals and sea anemones. Her latest research focuses on extending this understanding, identifying the processes behind coral's reaction to environmental change and stress.

Coral reefs are some of the most impressive and important ecosystems on our planet. They provide a habitat for over 25% of marine life, but they also provide a range of important services for our population, which include supporting fisheries and protecting coasts from erosion. Corals are cnidarians, a group of animals that also includes sea anemones.

Coral cover has seen a rapid, global decline over the past 40 years, a result of numerous stressors which can result in coral bleaching – a process in which the coral loses its symbiotic dinoflagellates (a group of microscopic and photosynthetic organisms that live within the coral's cells and provide nutrients to their hosts). For years, research in this area has focused on the environmental stresses on corals, including climate change and ocean acidification. However, Dr Weis' research focuses on the molecular interactions between these dinoflagellates and their coral hosts – a relationship that is at the core of a coral reef's ecosystem.

MUTUALISTIC RELATIONSHIPS

Symbiosis refers to a relationship between different species that live together in a close, long-term association. For example, one species may live directly on, or in, the other. In terms of corals and dinoflagellates, the relationship is mutualistic, where both species benefit from the dinoflagellates living inside the coral. The dinoflagellates photosynthesise and provide the coral with organic carbon, whilst the coral provides a stable refuge from grazing, and inorganic nutrients and a high light environment. The inner mechanisms of coral–dinoflagellate symbiosis are currently not well understood, and yet this relationship forms the basis of many reef functions.

This makes Dr Weis' research even more important. When the symbiosis between the coral and its dinoflagellates breaks down, the dinoflagellates leave the coral tissue,

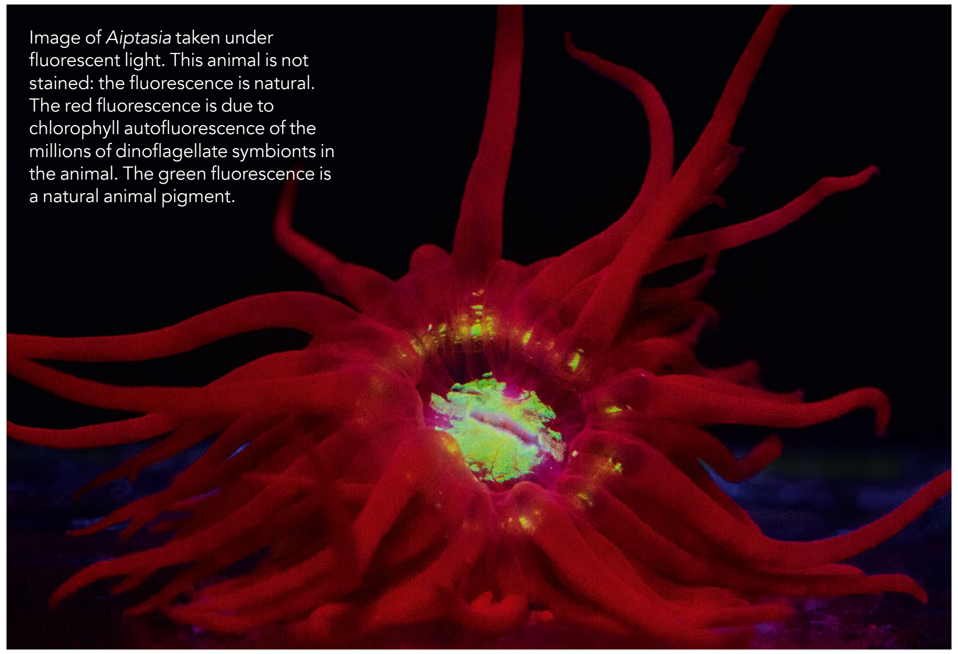


Image of *Aiptasia* taken under fluorescent light. This animal is not stained: the fluorescence is natural. The red fluorescence is due to chlorophyll autofluorescence of the millions of dinoflagellate symbionts in the animal. The green fluorescence is a natural animal pigment.

> **Dr Weis' research focuses on the molecular interactions between dinoflagellates and their coral hosts – a relationship at the core of a coral reef's ecosystem**

resulting in a "bleached" coral, which affects the coral's calcification process. This, in turn, affects the coral's ability to create a solid structure, which has widespread impact on the health of the reef itself. If bleached corals cannot re-establish a symbiosis with dinoflagellates they will die, which will, in turn, lead to reef destruction. One of the most important questions in this area, however, is whether it is the dinoflagellates that leave the coral when bleaching occurs, or if they are expelled by the coral itself.

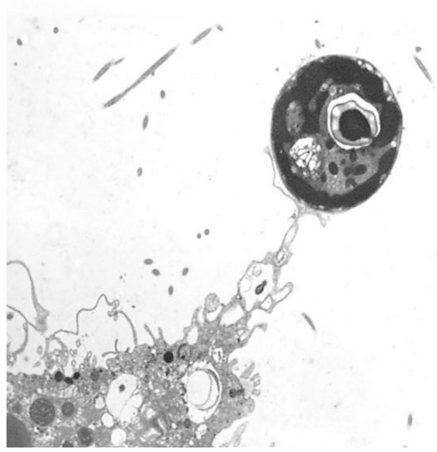
SEA ANEMONES

Corals are not the only cnidarians that have mutualistic relationships with symbiotic dinoflagellates – there are also species of sea anemones that have such interactions. While these are very different to corals and provide different services to the environment, they are easier to cultivate in a laboratory environment than coral itself, and they also undergo bleaching. As such, they provide a good model for studying and understanding the mechanisms of symbiosis between dinoflagellates and cnidarians. This understanding could then potentially be applied to corals, further supporting conservation efforts.

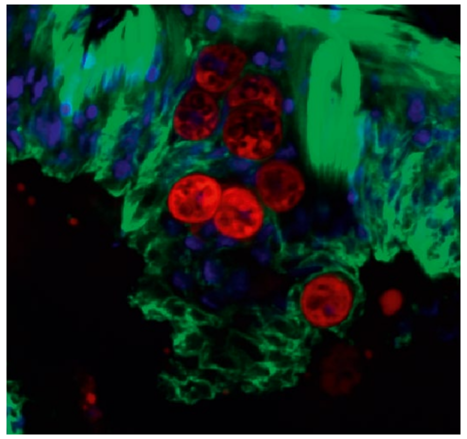
INTERACTIONS AT A MOLECULAR LEVEL

Through research by Dr Weis and her colleagues, a basic understanding now exists of the molecular processes responsible for the interaction between coral hosts and their dinoflagellate symbionts. The symbionts have been found to live within the digestive tract of the coral, inside compartments within host digestive cells.

In some species of cnidarians, the dinoflagellate cells are passed on to offspring through the mother, but in most cases, the algae enter the host after it has been established within the reef. How do these two organisms find each other, though? On a molecular level, signalling takes place between the host and the symbiont – many cnidarians have receptors which recognise molecular patterns on the symbiont cells, allowing them to bind together. The symbiont cells enter host tissues through phagocytosis, a process in which an organism's cells engulf a foreign body and absorb it into the body of the organism itself. This is considered to be a part of the coral's innate immune system, which recognises and destroys damaging invaders, while also identifying and nurturing positive foreign cells.



Transmission electron microscope image of a coral cell engulfing a dinoflagellate via phagocytosis. Pseudopods are evident partially surrounding the symbiont. For scale, alga is about 10 microns in diameter.



Confocal microscopy of closeup of *Aiptasia* digestive epithelium. Red is symbiotic algae from chlorophyll autofluorescence, blue is DAPI and staining animal nuclei, green is a stain for actin filaments – staining animal tissue. For scale, algae are about 10 microns in diameter.

Healthy reef on Heron Island, Great Barrier Reef, 2008

INNATE IMMUNITY

A set of genes called "scavenger receptors" (SR) have the ability to recognise numerous different microbes, and are a part of innate immunity in all animals – a system responsible for non-differential protection against damaging microbes. While humans also possess SR genes for the identification of invasive and dangerous microbes, cnidarians have been found to have a wider variety of such genes which may play a role in the recognition of symbiotic dinoflagellates by hosts.

In vertebrates, such as humans, the "complement system" recognises and destroys microbes. However, genes involved in this innate immune response have also been identified in anemones, and could have a role in the symbiotic relationship between cnidarians and dinoflagellates – although this is currently unclear.

An important component of immunity is tolerance to microbes as well as resistance to them, and a substance known as "Transforming Growth Factor beta" (TGFβ) promotes this tolerance in vertebrates. These substances have, likewise, been found in the anemone *Aiptasia pallida*, and are used in regulating the interactions with dinoflagellates. When TGFβ that had been isolated from humans was added to these anemones, the bleaching response that would typically occur when the animal is exposed to heat was suppressed.

Dinoflagellate cells, when entering cnidarian hosts, "activate" a TGFβ pathway. This process is parallel to that employed by some single-celled parasites such as *Plasmodium*, which causes malaria, and *Trypanosoma*, which causes sleeping sickness. If these processes are understood in anemones, it could help to improve understanding around how these parasites enter the human body, allowing a method to be found capable of reducing parasitic infection.

This area is at the forefront of cnidarian–dinoflagellate symbiosis research and is an exciting and developing field which will prove highly important in understanding the basis for reef and coral functions. Understanding these processes may help researchers to supress bleaching responses by coral and buffer against the effects of climatic and environmental change.

Cnidarian-dinoflagellate research is an exciting and developing field which will prove highly important in understanding the basis for reef and coral functions

FUTURE DIRECTION

Further understanding of the processes involved in this symbiotic relationship can aid in identifying the processes behind corals' reactions to environmental change and stress, and the factors that determine a coral's sensitivity to environmental change. This knowledge could then be used to identify how different species of coral are likely to respond to different stressors, including climate change and global warming. Ultimately, this will further aid conservation efforts in preserving and protecting these important species.

Coral reefs support thousands of species globally, and with swathes of reefs across the planet in a critical, bleached state, Dr Weis' research is incredibly important for conserving such areas in years to come.

Q&A

How important is the relationship between corals and dinoflagellates to the health of the reef?

All reef-building corals are symbiotic with dinoflagellates. And these corals are the trees in the forests for coral reefs. They form the trophic and structural foundation of the ecosystem. Without corals, there are no coral reefs. Therefore, the health of the symbiosis is essential and central to reef health.

We often hear reports that the health of reefs is in rapid decline. What direction do you believe future research could take to combat this?

Research needs to focus on several levels. Ecologists are focusing on understanding the features of coral reefs that build resilience and resistance to decline. Conservation biologists are studying the best practices for reef restoration after stress events. Coral biologists like me are studying the molecular and genetic components that help us determine whether and how corals can withstand impacts of climate change. Are there certain species or populations of corals that are resistant to stress? Can we breed corals that have improved fitness in warmer, more acidic oceans?

In terms of immunity, how similar are the innate immune systems of cnidarians and humans?

Very similar. When one studies the genomes of ancestral organisms like cnidarians and compares them with highly derived organisms like humans, one finds that almost all of the innate immunity genes, pathways and mechanisms are shared between these very distantly-related organisms. What this suggests is that these were all present in the last common ancestor before these organisms diverged hundreds of millions of years ago. Since their divergence, modifications and elaborations of these genes have occurred within different animal groups. However, the basic functioning of these pathways to attack negative invaders and nurture and tolerate beneficial microbes remains the same between the groups.

How easy is it to relate models based on sea anemones to corals, and what challenges does this method of experimentation face?

Sea anemones are very powerful models for the study of corals. They share very similar genomes and in many cases, harbour identical or very closely related dinoflagellate symbionts. The chief limitation to sea anemones as models for corals is their absence of a calcified skeleton. Therefore, any biology associated with coral calcification and the impact of ocean acidification on coral biology cannot be studied in sea anemones. (The absence of a skeleton is, ironically a key strength to anemones as tractable laboratory models because exoskeletons make the study of cell biology very difficult.)

What implications do you believe your research has for the future of coral reefs?

My research is providing critical foundational knowledge on the symbiosis that underpins healthy corals. All applied and translational science and policy aimed at saving and preserving reefs for the future relies on foundational studies that are and have been performed by hundreds of coral biologists across the globe.

Detail

RESEARCH OBJECTIVES

Dr Weis' research investigates the cellular and molecular interactions between cnidarians, such as corals and anemones, and their photosynthetic dinoflagellate symbionts.

FUNDING

National Science Foundation (NSF)

COLLABORATORS

Simon Davy, Victoria University of Wellington, New Zealand

BIO

Dr Weis has been on the faculty at Oregon State University since 1996. She obtained her BS from Yale University in 1984, before studying her thesis at the University of California Los Angeles between 1985 and 1990. It was during this time that she established her career-long interest in coral-dinoflagellate symbiosis.

CONTACT

Virginia M Weis, PhD
Professor and Head
Department of Integrative Biology
3029 Cordley Hall
Oregon State University
Corvallis, OR 97331
USA

T: +1 541 737 4359
E: weisv@oregonstate.edu
W: http://weis.science.oregonstate.edu/
W: http://ib.oregonstate.edu/

@VirginiaMWeis
@WeisLab