Biochemical warfare on coral reefs

In a coevolutionary struggle, invertebrate adversaries develop weapons and counterweapons

By Kristen Whalen

Just beneath the tranquil, clear waters of the tropical Caribbean, unseen by all but a few keen-eyed divers, two foes have engaged in a life-and-death struggle every day for thousands of millennia. Their limestone battlefield is peppered with limitless varieties of soft coral that look like easy targets for any hungry passerby. However, looks can be deceiving. These outwardly innocuous corals, commonly known as gorgonians, have a few tricks up their soft sleeves. They have evolved a powerful arsenal of chemical toxins that leave all who dare to consume them with a mouthful of distasteful compounds and a lesson they won't soon forget.

The gorgonians' chemical defenses do an excellent job of deterring most fish and other large predators. But a handful of reef inhabitants has learned how to navigate the gorgonians' toxic chemical minefield and exploit these abundant corals for both food and shelter, giving themselves an edge over their fellow reef competitors.

A sea snail's all-you-can-eat (toxic) buffet

At first glance the reclusive sea snail *Cyphoma gibbosum*, known as a "flamingo tongue" to most Floridians, appears harmless, even skittish. It retracts its ornate mantle tissues inside its cream-colored shell at the mere passing of a shadow overhead. Yet this single species of sea snail, no bigger than a postage stamp, has an insatiable appetite for gorgonians. This predator inflicts damage to more gorgonian colonies per year than even the most destructive hurricane.

Cyphoma leave an unmistakable trail of feeding scars on gorgonians. The snails usually feed in roving hordes, munching their way through toxin-saturated tissue down to the corals' hard skeleton. The sea snails use a modified tooth called a radula, chewing down long lines of tissue in a fashion similar to mowing a lawn. How this molluscan predator can overcome the gorgonians' toxic chemical defenses—a feat unparalleled by the thousands of competing consumers on the reef—was the mystery I hoped to solve.

Before I entered the MIT/WHOI Joint

Ann Tarrant, WHOI

Kristen Whalen, a graduate student in the MIT/WHOI Joint Program, collects gorgonian corals in the Exuma Islands in the Bahamas to analyze the toxic chemical compounds they produce as a defense against hungry predators.


Kristin Whalen, WHOI

An orange-speckled snail, *Cyphoma gibbosum*, munches its way up one of its favorite meals, a purple gorgonian with brown grass-like polyps named *Biareum asbestinum*, known locally as "dead man's fingers" because of its knobby, branched appearance.


Kristin Whalen, WHOI

Over evolutionary time, soft corals developed poisonous compounds to deter predators, while the marine snail *Cyphoma* evolved a collection of genes and proteins called a "defensome" to detoxify coral compounds and allow it to feed on the corals.

Program in 2002, I was introduced to the field of chemical ecology as an undergraduate at the University of North Carolina, Wilmington. Three times a year, we would pack up the lab, grab our wetsuits, and head south to the Florida Keys and the Bahamas to conduct experiments to assess the chemical defenses of Caribbean sponges.

Sponges in many ways are similar to their gorgonian cousins in that both are attached to the bottom and exposed to predators. Furthermore, both use similar noxious compounds to defend themselves against hungry predators.

During forays into the field to study sponges, my attention strayed to their coral neighbors, where I caught my first glimpse of *Cyphoma* happily nibbling away on its toxic coral diet. I wondered how this snail was able to beat the system and consume a diet so rich in toxins and yet appear no worse for the wear. Little did I know that the answer would come from understanding how the human body is able to cope with chemicals.

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In humans, the liver acts as the body's filter. It breaks down and excretes a wide range of chemicals including drugs, alcohol, man-made toxicants, and naturally derived compounds found in our food. The processes controlling this incredible feat are carried out by a network of genes and enzymes, collectively termed a "defensome," which protect our bodies from chemical intoxication.

Akin to the human liver, the digestive gland in *Cyphoma* is thought to contain genes and enzymes that carry out functions similar to their human counterparts. *Cyphoma*'s defensome, however, has been fine-tuned over evolutionary time to handle the marine toxins that these snails encounter.

Working with my Ph.D. advisor, Mark Hahn, a biologist at Woods Hole Oceanographic Institution, I have attempted to identify the genes and enzymes in the gut of *Cyphoma* that allow them to overcome the biochemical barrier imposed by the coral. Using our knowledge of gorgonian coral chemistry, we identified families of genes and enzymes in humans that would likely be responsible for metabolizing toxic compounds. With this genetic blueprint, we looked for these same families of genes and enzymes in *Cyphoma*.

Kristen Whalen, WHOI

A variety of corals inhabit the warm, shallow waters surrounding the Bahamas' Exuma Islands, including soft corals also known as gorgonians, such as sea fans (just right of center), sea whips (far right and far left), and sea plumes (in front of the large lavender sea fan).

Once we identified several possible detoxification genes in sea snails, the next step was to examine how these genes responded to the gorgonian compounds. In 2006, I collected sea snails and gorgonians from shallow reefs near the Perry Institute of Marine Science (PIMS) in the Bahamas. Back at the PIMS laboratory, I allowed the sea snails to feed on either a gorgonian diet or a control diet lacking any coral compounds to examine how the genes were "expressed," or activated, when the sea snail was exposed to gorgonian compounds.

I found that the expression of one group of detoxification genes is "ramped up" in the digestive glands of *Cyphoma* feeding on specific gorgonian diets. These sea snail genes likely encode enzymes that are able to metabolize the very coral compounds responsible for their increased expression. These enzymes work by slapping an oxygen molecule onto the chemical intruder, making it more water soluble and easier for the cell to excrete. But it seems that this family of enzymes is capable of responding to and detoxifying only a narrow range of coral compounds.

In contrast, a second family of enzymes was highly expressed in the digestive gland of *Cyphoma*, regardless of the gorgonian diet. These enzymes assist by tagging the toxin with a special chemical flag, signaling the cell to expel the toxin through gated pumps in the cell membrane. A follow-up series of experiments concluded that these proteins likely function as all-purpose detoxification enzymes, capable of "tagging" a broad range of gorgonian compounds.

Together, these results suggest that *Cyphoma*'s defensome comprises genes and enzymes that have both specific and varied detoxification roles, but work in concert to protect this predator from its toxin-laden prey.

For now the score appears to be *Cyphoma* 1, gorgonians 0—but I wouldn't count the corals out of this coevolutionary arms race just yet. If evolutionary theory has taught us anything, gorgonians are quietly developing novel toxins through spontaneous genetic mutation events that may one day tilt an adaptive advantage in their direction. My advice to spectators: Stay tuned for the next 10,000 years of coevolution.

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Kristen Whalen earned her B.S. in marine biology in 2001 at the University of North Carolina, Wilmington, and her Ph.D. in the MIT/WHOI Joint Program in biological oceanography in June 2008. In September 2008, she embarked on a new adventure that took her to the temperate rocky reefs of Sydney, Australia. As a National Science Foundation International Postdoctoral Fellow, she will investigate how marine herbivores, such as sea urchins, are able to cope with the toxins in their diet. Considered the "sheep of the sea," sea urchins can consume fields of fleshy macroalgae that are full of toxins. How they do it has remained a mystery. With technology developed at the University of California, Santa Barbara, Whalen will be able to home in on the handful of genes—out of thousands—that protect these marine herbivores from toxins they eat. When Whalen is not scuba diving for her research subjects, she enjoys oil painting. She coached the WHOI Biology Department softball team, also known as the "Redfielders" (the Bio Department is housed in the Redfield Building).

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