TO Banish Biofouling

Can a new approach help sailors prevent barnacles and algae from coating ship hulls?

by Cherie Winner

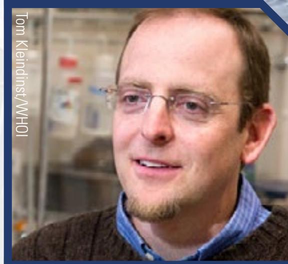
Norm Farr/WHOI

As long as sailors have been going down to the sea in ships, they have been coming back with their ships' hulls coated with barnacles, algae, and slimy gunk.

And for just as long, mariners have searched for ways to repel and remove the adhesive organisms. Solutions ranged from scraping the hulls with heavy chains to electrifying the water around vessels, coating the hulls with glass, and turning entire ships into magnets.

Yet "biofouling," as it is called, continues to plague ships.

"For millennia, mariners have sought ways to prevent biofouling," said Ben Van Mooy, a biochemist at Woods Hole Oceanographic Institution (WHOI). "It's a really, really difficult problem."


Tom Kleindinst/WHOI

WHOI marine biochemist Ben Van Mooy

It's also very, very expensive. A 2011 study estimated that biofouling increases frictional drag on ships so much that it costs the U.S. Navy $180 million to $260 million per year in added fuel use.

Then there's the cost of taking ships out of service for a few weeks and putting them into dry dock so the hangers-on can be scraped off or dislodged with high-pressure jets of water; and the cost of preventive measures that enable ships to get by with a scraping every two years, rather than every few months.

Add in other nations' military ships, fishing, and recreational boats, and thousands of commercial vessels, and the global costs of biofouling are exorbitant.

To combat this age-old scourge, Van Mooy has sought to unravel the complex biological factors that enable marine organisms to attach to and accumulate on hard surfaces. He is revealing strategic points in the process where people might be able to intercede—and finally win.

Tiny beginnings

Biofouling starts at the microscopic level, with a slippery layer of bacteria that larger organisms attach to (and sometimes eat).

"If you clean a ship or put a new ship to sea, it's coated with microbes within a day," said Van Mooy. "Not enough to see, but the first microbes are starting to lie down. And then the slime begins to grow over the course of weeks. That is essentially a gateway community to the barnacles and other things."

"The slime" is a biofilm, a thin sheet of bacteria connected by a matrix of molecules they exude to communicate with each other and to provide a hospitable environment for themselves. Once the slime forms, the rush is on, as algae and the larvae of creatures such as barnacles attach and begin to grow.

Their growth is impressive. Routine scraping of average-size commercial vessels can yield up to 200 tons of organisms. And that's just the fouling on hulls. Of equal concern are the pipes, ranging up to a foot in diameter, that move cold seawater through a ship's heat-generating mechanical systems.

"We pump tons of seawater through piping on the ship," said WHOI Port Engineer Dutch Wegman, who deals with biofouling on the institution's research vessels. "You get fouling inside the piping, which reduces the flow. Then we might not be able to cool our engines well, and so we lose speed because we can't go to full power. It can be a real problem."

Fending off fouling

With the high costs of removing organisms from ships and the even higher costs of *not* removing them, inventors and ship operators have come up with hundreds of methods for reducing biofouling. Almost all of the would-be solutions have been variations on two themes: prevent organisms from sticking to the hull, or poison them if they do.

In the era of wooden hulls, the primary threat came not from barnacles that attached to the outside of ships, but from marine worms—actually, long, thin, soft-bodied clams—that tunneled through the wood. The Romans used lead sheeting to protect against shipworms, giving their ships an edge in commerce and in war. The hulls still had to be scraped, but at least the wood remained strong.

In the mid-1700s, the British began sheathing ship bottoms with copper, which repelled barnacles and other organisms as well as warded off wood-wasting worms.

"That was a *radical* technical advance," said Van Mooy. "It was probably one of the things that contributed to the emergence of England as a naval superpower in the 18th century."

For a few decades, copper sheathing was all the rage; but when steel hulls came into use in the 1800s, copper could no longer be employed because it hastened corrosion of the steel. Steel by itself is susceptible to slime, algae, and barnacles, so once more, the hunt was on for a way to combat biofouling. The most popular solution, and the one still in use today: paint.

Preventive paints

The success of copper sheathing prompted ship owners to try coating their hulls with paint containing copper. The idea was that trace amounts of copper would leach into the water, poisoning any small organisms nearby. Several other toxic ingredients were also tried, including arsenic, mercury, strychnine, cyanide, and radioactive materials. A 1952 review of their performance by WHOI scientists indicated that some of the formulations worked well against barnacles. It did not mention what effects they had on the people who applied them.

Wegman recalled that the WHOI ship *Oceanus* was among the first to use tin-based antifouling paints. It was so effective that the ship still didn't need to be scraped five years later. "Tin was wonderful," he said. "But it's a funeral of death—everywhere it went, it was killing off, to some extent, everything around it."

So tin-based paints were banned. The U.S. Navy and WHOI now use the old standby, copper-based antifouling paint. But as with tin paints, the very reason it works has become a matter of concern.

"The reason this paint is so good is that it is a really, *really* effective toxin," said Van Mooy. "Now copper is being outlawed, because ships come into port and slough off all this copper and contaminate the harbor. So the Navy's got a problem."

Recognizing the dangers of toxic coatings, paint developers came up with slippery "fouling release" paints that defeat biofouling not by killing the organisms, but by making it impossible for them to stick to the ship. Microbes and larger organisms can attach to it when a ship is in dock or moving slowly, but when the ship moves quickly, the force of water moving past the hull knocks them off.

That's an effective approach for ships, such as commercial vessels, that go fast and spend most of their time on the move. But it's much less useful for those that spend a lot of time in port or holding still at one site.

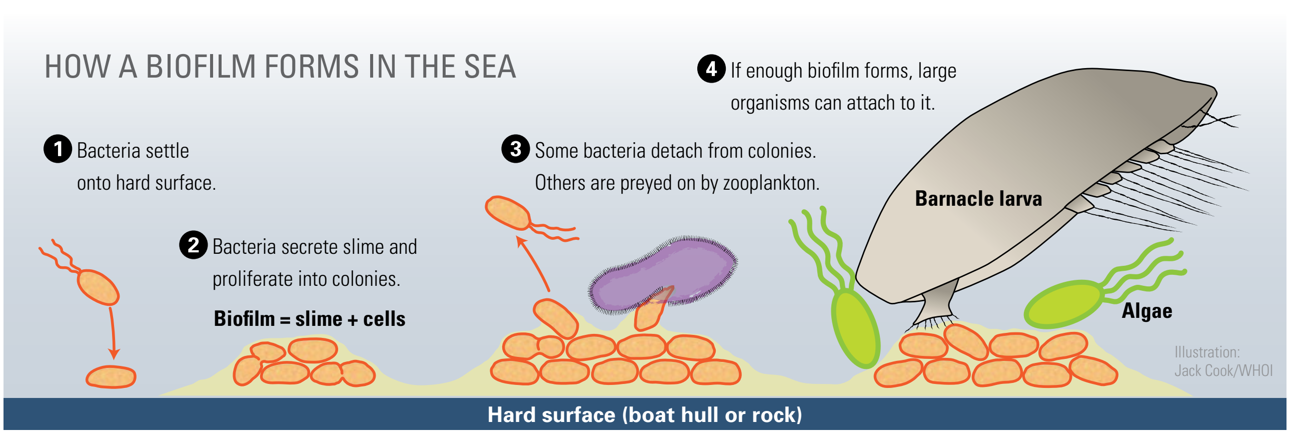
"A lot of these ships that cruise at 25 to 30 knots love it," said Wegman. "But with an oceanographic research ship, first of all, we're slow going out"—top speed for WHOI vessels is 11 knots—"and then we stop at the study site. So the slippery stuff didn't work for oceanography at all." It's also not a solution for the Navy, whose ships are in port about 80 percent of the time.

New targets

Van Mooy studies the ecology of ocean microbes, and since forming biofilms is a fundamental way of life for them, he has long been interested in the process. But he hadn't made the connection to the fouling of ship hulls until the manager of the Navy's program on biofouling research invited him to submit a research proposal to understand the process in more detail and identify potential targets for antifouling measures.

"I'm not really working on *solving* the problem, I'm working on *understanding* the problem," Van Mooy said. "Materials scientists and paint designers are coming up with new technologies to prevent biofouling. But those aren't going to work unless they know what processes to target with the new technologies."

Most fouling prevention efforts have focused on the ability of organisms to attach to the ship and proliferate there. But microbial biofilms don't just keep getting thicker and denser, said Van Mooy. Some of the bacteria detach from the biofilm and return to a free-floating existence, perhaps in search of a less-crowded surface to colonize. Many of the bacteria that do stay attached are harvested by grazing protists or other zooplankton.



"This is very basic information that, surprisingly, is still just completely unknown" in the context of ship fouling, said Van Mooy. And that raises intriguing possibilities: Could boosting detachment or predation prevent biofouling?

A four-step approach

Van Mooy measured four key aspects of biofilm production: settlement, attachment, detachment, and predation. He used metal plates about the size of standard notebook paper, leaving some parts of the plates bare and coating others with antifouling treatments. Then he attached the plates to pylons just below the sea surface in Vineyard Sound off Cape Cod.

"I put them out in the environment and let real communities do their thing," he said. "Ninety percent of the research in this field is focused on doing culture work—you take a plate like this and you go into the lab and throw it in with your favorite bacteria"—lab-grown cells that are the microbial equivalents of white lab rats. "People test their coatings against these model organisms, and they perform brilliantly. Then they put 'em in the ocean, and BAM!, they're terrible."

He left his test plates in seawater long enough to grow robust natural biofilms. Then he brought the slimy plates into the lab and put them into narrow tanks, each bathed by a continuous flow of seawater. He then let the biofilms continue to grow for 24 hours, so he could observe them over one complete daily solar cycle.

Some tanks received water fresh from Vineyard Sound, which contained other bacteria (that could settle onto the plate) and protists (that could eat biofilm cells).

Other tanks received water that had been filtered to remove bacteria that might settle onto the plates, and yet other tanks received water filtered to remove protists and thus eliminate predation on the bacteria. These experiments allowed Van Mooy to estimate how settlement, attachment, detachment, and predation contribute to or hinder biofilm formation.

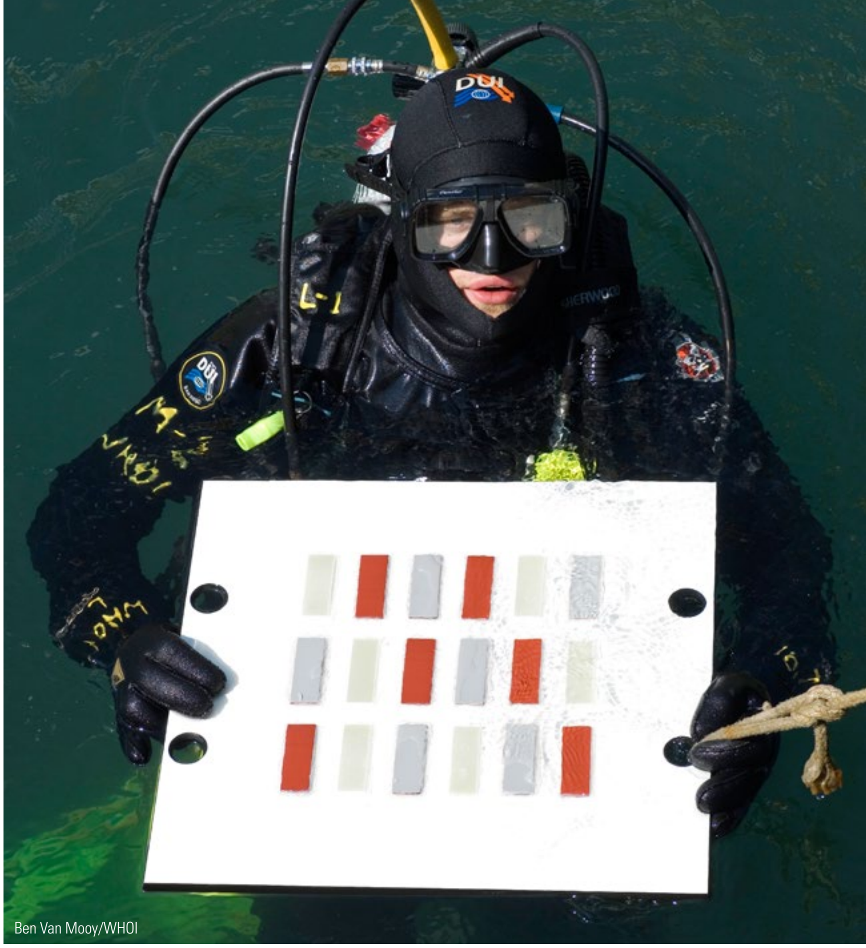
Van Mooy was pleased that his approach verified that copper-containing paints don't stop microbes from settling, but kill them soon after they attach. The experiments also showed that accumulation of bacteria on a "fouling release" coating, which is not toxic, was almost 100 times faster than on the copper paint. Bacteria formed a healthy biofilm on the slick coating because the water flowing past it was not moving fast enough to dislodge them.

Zeroing in

Those results confirmed that his experimental setup worked, but the real payoff came from looking at the processes that had not been studied in detail before. Van Mooy found that in the summer, biofilms grew fast but then leveled off as predators took a toll. In winter, growth was slower but cells still accumulated because grazing by zooplankton was also lower.

Most exciting of all was how big a factor predation was. In both seasons, it accounted for about one-third of the loss of cells. The rest was due to detachment.

"Until we had done this experiment, we really didn't know how big the predation rate was," said Van Mooy. "Some people thought it might be really small compared with detachment. What this experiment is telling me is that one way to develop a new coating may be to encourage predation. Is there something you could put in paint that would attract the microscopic grazers to come and 'mow the lawn' for you?"


Ben Van Mooy/WHOI

WHOI researcher Byron Pedler puts plates into the sea as platforms to grow natural biofilms. The strips are hull material coated with copper-containing paint (red), fouling-release paint (gray), or left uncoated.

He's pressing that suggestion on the biofouling community, nudging engineers and paint designers to consider new approaches. "I keep telling these guys: 'You can't spend your whole life focusing on stopping settlement. You've abandoned fighting proliferation, because you don't want toxic coatings. The detachment angle doesn't seem to be panning out for naval ships. So you should start working on grazing.' "

A WHOI legacy

Van Mooy's experiments extend a long tradition of biofouling research at WHOI. In the years leading up to and during World War II, the Navy gave WHOI scientists a wealth of funding to work on biofouling. It was the first federally sponsored research program at WHOI and the first effort anywhere to integrate basic research on biofouling with its prevention. After the war, the Navy commended WHOI scientists for advancing scientific knowledge of the fouling process and antifouling measures and saving it millions of dollars.

Wegman, who has dealt with biofouling throughout his 36-year WHOI career, is intrigued that tiny predators could become allies in the never-ending battle against fouling organisms.

"Isn't that the joy of working at Woods Hole Oceanographic?" he said. "Here we are, banging our heads against that wall, and we've got this guy over here saying, 'Why don't we look at it from a different direction?' " ▲

This research is sponsored by the Office of Naval Research.