WHAT'S NEXT FOR RED TIDE?

BY HAYLEY RUTGER

A Florida resident checks her hurricane forecasts all summer long, looking at spaghetti models of where the next storm will go and reading news stories about the outlook for hurricane season and how climate change might be intensifying storms.

But as fall approaches, another phenomenon in the Gulf of Mexico worries her. Red tide is showing up sporadically in local waters, as it typically does at this time of year. How bad will it be, how long will it last, and why is that so much harder to predict for red tides than for hurricanes?

A LIVING STORM

Like a major hurricane, a bad bloom of red tide in Florida involves a perfect storm of environmental conditions. On top of that, red tide is alive—made of microscopic, toxin-producing algae of the species *Karenia brevis*—and its life and death are complicated.

That hasn't stopped a team of scientists led by Mote Marine Laboratory from picking it apart. Their goal: Break down what conditions may intensify, lengthen—or on the flip side, terminate—these red tides, and use that knowledge to build better mathematical simulations, or models, of red tide than we have today. From there, run those models to answer communities' big questions about what is making a given red tide severe or mild, what it might do next, or how a red tide might behave in hypothetical scenarios—for example, with projected increases in water temperature or rainfall due to climate change, altered levels of nutrients released into the water by human activity, or even with mitigation efforts to reduce its impacts.

RED TIDE'S 'KEY PLAYERS'

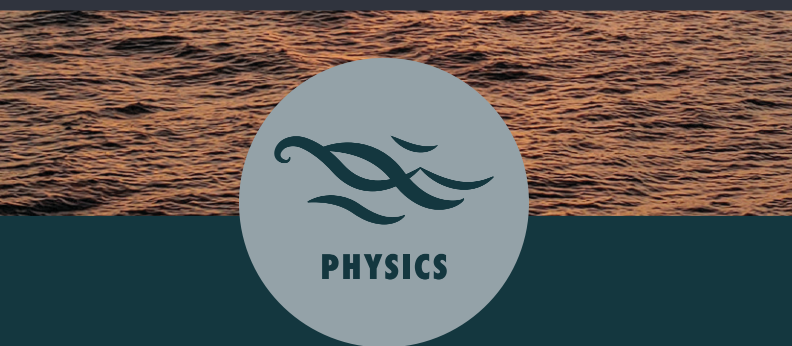
Gulf Coast residents and visitors might have heard scientists say that "red tide is complex," and there isn't a single reason why a bloom is bad or a single best strategy to fight bloom impacts. That's true, but it can be hard to appreciate when red tide toxins are irritating beachgoers' throats, causing dead fish and wildlife to wash ashore, closing shellfish farms and driving tourists away.

The good news is: By embracing red tide's complexity through decades of research, Mote scientists and their partners are bringing us closer to understanding what features of blooms and their environment are key players—pieces that give us the strongest signals for modeling what drives a bloom and what it might do.

"You have to figure out which organisms and processes are important in a bloom; it's not just *Karenia,*" said Dr. Cynthia Heil, Director of the Red Tide Institute at Mote and leader of the ongoing project "Life and Death of *Karenia brevis* Blooms in the Eastern Gulf of Mexico," which is funded by the National Oceanic and Atmospheric Administration (NOAA) Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) program.

Finding the key reasons and signals that a bloom will intensify or weaken, persist or terminate, is a major focus of this project, which includes scientists from Mote, Bigelow Laboratory for Ocean Sciences, the Florida Fish and Wildlife Conservation Commission

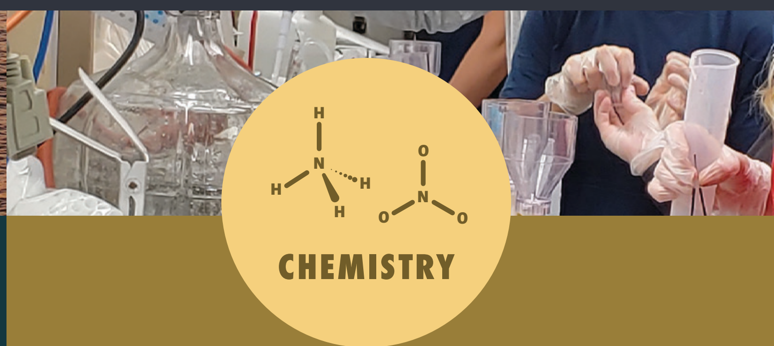
UNCOVERING RED TIDE'S KEY PLAYERS:



Water movement can help make or break a bloom. It's a key player in existing models made by USF and partners—for example, patterns in the Gulf of Mexico's Loop Current help USF forecast whether offshore environmental conditions will favor red tide formation in a given year. Water movement can also disperse blooms—so it's important for modeling and predicting bloom termination.

Temperature, salinity, oxygen & other physical conditions influence blooms. Notably, we're still learning what temperatures *Karenia brevis* can handle. See Biology.

Physical conditions tell us a lot, but many red tide questions call for modeling physics, chemistry, biology and ecology combined—a longtime goal boosted by the current Mote-led project.



At least 13 nutrient sources can "feed" *K. brevis* blooms, according to studies by Mote, Bigelow, FWC, UMCES and others. Mote and partners are investigating how to represent key sources in models.

Does heavy rain help blooms linger? It depends on timing. Mote scientists reviewed historical records and found that more intense rainy seasons —which could be increasing due to climate change—may coincide with existing red tide events lingering later than normal into summer. More research is needed to determine if a direct causative relationship exists, however.

Fish kills due to red tide are important sources of ammonia that helps sustain blooms, past studies showed. In 2021, scientists at University of Tampa and Mote used new detection tools to better map ammonia in Tampa Bay, finding it was enriched around patches of dead fish.

(FWC), New York University-Abu Dhabi (NYU), University of Maryland Center for Environmental Sciences (UMCES), and University of South Florida (USF). Each partner brings expertise on different components of red tides and the mathematical modeling tools that could help simulate them.

"We already know some of the key players in red tides," Heil said. "For example, we know *Trichodesmium* (a type of saltwater blue-green algae, or cyanobacteria) can fix nitrogen gas from the atmosphere into a nutrient source that *Karenia* can use offshore, where these red tide blooms initially begin, typically in low nutrient waters. We also know some major sources of nutrients for blooms that have moved closer to shore."

"But in some cases, we don't know as much—especially about bloom termination," Heil continued. "For instance, why do most blooms end within five to seven months but some last longer?"

Blooms often start in late summer to early fall, and some last through winter, but few continue past April. Project partners have found four major patterns of bloom termination by

Above: Mote scientists and partners collect chemical and biological samples during a research cruise in December 2021. **Page 13 photo**: Gulf of Mexico waters. CREDIT BOTH: JOAQUÍN MARTÍNEZ MARTÍNEZ/ BIGELOW LABORATORY FOR OCEAN SCIENCES

A SAMPLE OF THE SCIENCE TO IMPROVE MODELING & FORECASTS

We know the basic biology of *K. brevis* thanks to decades of research by Mote, FWC, NOAA and others on its growth, nutrient uptake, photosynthesis and toxin dynamics, for example—and we need to continue learning. Red tide biology research on land and at sea is in high demand to help build models that represent red tide more realistically.

Red tide algae are monitored regularly through teamwork by FWC, Mote and many others. Supporting red tide detection and sampling will help provide better data for models & forecasts.

Can it take the heat? Past lab studies suggest *K. brevis* becomes stressed as water temperatures approach 86 degrees Fahrenheit, but in summer 2018, Mote scientists reported a bloom persisting at up to 93 degrees! Clarifying red tide's temperature tolerance will support modeling and predictions about how blooms will respond to our changing climate.

It's not just *K. brevis*. Scientists know *K. brevis* can use nitrogen nutrients released by *Trichodesmium,* a type of saltwater blue-green algae (cyanobacteria) that can "fix" nitrogen gas from the atmosphere into a form *K. brevis* can use. And that's just one of many living things that can influence red tide—for better or worse.

It's an algae-eat-algae world: *K. brevis* can graze on saltwater blue-green algae called *Synechococcus* as a nutrient source. How that plays into *K. brevis'* life is one of the biggest mysteries that scientists, particularly at Mote and UMD, are working to pin down for realistic red tide modeling.

Red tide has a microbiome. *K. brevis* can be surrounded by bacteria and viruses that can help or harm it, note scientists at Mote, Bigelow and NYU. Representing this in red tide models is a new frontier.

analyzing bloom data from 1998-2021. Understanding what drives these patterns could improve bloom prediction and monitoring.

Some blooms, however, last all the way into the next summer. Certain summer blooms—like the one in 2017–2019—become infamous for their prolonged impacts on coastal communities. What allows these blooms to persist, while others terminate, is one of the biggest questions that Heil and her fellow scientists aim to answer in the NOAA ECOHAB project. By finding out, the team could improve mathematical models to address one of the public's biggest questions, "How long will this bloom last?"

To better understand summer blooms, Mote scientists delved into FWC's historical red tide records and other long-term data—including mid-century records kept by Mote's founding "Shark Lady," Dr. Eugenie Clark. Long term data help the team examine whether warmer winters due to climate change are helping red tide overwinter, and whether rainier summers might be tied to longer red tides—based on the concept that more rain could bring more land-based nutrients to existing coastal blooms. In related research, UMCES scientists are examining whether the concentration of red tide cells varies with the amount of rainwater flowing from Florida's Peace River and with climate variables that affect rain, namely, the repeating patterns of "El Niño" and "La Niña" climate conditions that scientists know as ENSO—El Niño Southern Oscillation.

The jury's still out on these possibilities, but one preliminary finding calls for more investigation: "Non-summer-bloom years experience considerably less rainfall over the wet season compared with summer bloom years by almost an order of magnitude," Heil wrote in a June 2022 project report. "This knowledge will enhance modeling and prediction efforts."

NEVER ENOUGH OBSERVATIONS

"When weather predictions first started in the late 1950s, the results were terrible, but as more and more observations became available, the models got better, and we now, some six decades later, have pretty good weather forecasts," said Dr. Robert Weisberg, Professor Emeritus at USF College of Marine Science and a co-principal investigator on the current project, together with USF Associate Research Professor Dr. Yonggang Liu.

"There are never enough observations to fully specify a complex phenomenon," Weisberg continued. In other words, we can't monitor all of the red tide algae and the conditions around them all the time, so scientists use mathematical models to connect some of the dots between their real-world observations.

"But models are also necessarily incomplete because they require certain assumptions and have errors that grow in time and space," Weisberg said. Just think of a hurricane's cone of uncertainty, which widens as it stretches away from the present time and location.

"So models and observations are best done in a coordinated manner. The observations help to refine and keep the models 'honest,' and the models help to fill in the observational gaps."

USF partners are building upon their current physical ocean modeling for the Mote-led project. USF and FWC already produce four-and-a-half day forecasts of where existing red tide algae may travel, using the physical properties of water movement and real counts of red tide cells provided by FWC, Mote and others. USF has also used a different type of model to make seasonal predictions of whether a bad red tide is likely, based on fluctuations in the Gulf's Loop Current that are believed to change nutrient dynamics offshore. Their model was tested against 29 years of red tide data and it answered correctly—"yes there will be a major bloom," or "no, there won't"—for 24 years.

Such tools are valuable, but physical models alone probably cannot answer some of the biggest questions about red tide—for instance, which blooms will terminate or last through summer. That could require adding biology, ecology, chemistry and geology data to models—and project scientists at Mote, Bigelow, FWC, NYU, UMCES and USF are each working on key pieces.

In the current project, spanning 2019 through 2024, Heil and Mote Postdoctoral Scientist Dr. Tristyn Bercel are leading monthly water sampling and annual "process cruises" where multiple partnering scientists collect many kinds of samples and data from southwest Florida waters and perform certain experiments right on the research vessel.

Bercel said: "Out there we get the whole bloom in context, and in the lab we can use samples and cultures of *Karenia* to investigate specific questions further."

NOAA ECOHAB support has been essential for this group effort. "These ECOHAB multi-year regional projects help you bring in an interdisciplinary team," said Heil, who has participated in all three regional ECOHAB projects about *K. brevis* red tide, first as a postdoctoral scientist in the late 1990s and then twice more as a leader.

"When I first started out, harmful algal bloom science was a backwater, compared to how it is today," Heil said. But through the efforts of research by many scientists and support of programs like NOAA ECOHAB, she said, "We've gained basic knowledge about the system and red tide's role in the system—the cell levels, how they take up nutrients, how they're grazed, and the annual dynamics of the West Florida Shelf (the environment where these red tides occur), including currents and local and offshore inputs of nutrients."

MODEL THIS MESS

Some of the most complicated things to work into a red tide mathematical model are biology and ecology—the life of red tide algae and its relationship to the world around it. Living things are harder to describe with fundamental, mathematical rules than physical forces are, and they come with wider margins of error.

It's hard enough just to keep track of where red tide is—through countless hours collecting and analyzing water samples and comparing them with satellite imagery of the ocean surface. It takes even more time, expertise and expensive instruments to document how and what the algal cells are doing—for example, how fast do they photosynthesize, capturing sunlight to produce energy-rich molecules they need for growth and survival?

Complicating things further, *K. brevis* doesn't behave the same way all the time. It can take up nutrients from its environment and capture energy from the sun (like a plant), but it can also get nutrition and energy by grazing (like an animal) on other microscopic critters. In particular, it seems to graze on saltwater blue-green algae (cyanobacteria) called *Synechococcus*.

That mixed lifestyle is called mixotrophy. "The easiest way to understand microbial mixotrophs is that they are the venus flytraps of the microbial world," said Dr. Pat Glibert, Professor at UMCES Center for Environmental Science and co-principal investigator in the current project.

Glibert and her colleagues at UMCES, along with Bercel and Heil at Mote, are all investigating this "venus flytrap" behavior in *K. brevis* because it could play a role in modeling and forecasting some important red tide processes. For example, what happens to microscopic algae, including red tide, when nutrient-rich wastewater is spilled into the Gulf of Mexico?

Heil, Glibert and others observed that process in spring 2021, after a disastrous spill of nutrient-rich wastewater from the former phosphate processing facility at Piney Point into Tampa Bay. "In response to Piney Point, we had a bloom of diatoms," algae that can compete with *Karenia brevis*, Heil said. "But an already high abundance of *Karenia* was able to continue for the rest of the summer."

Mote scientists collected a limited set of samples from the spill area in April 2021 for experimental studies. Those samples contained abundant *Synechococcus*. When those samples were combined with the *K. brevis* bloom samples in various concentrations in a lab study, the *Synechococcus* disappeared. "It's a strong indication that mixotrophy was likely to have occurred," Heil said.

Knowing *K. brevis* uses mixotrophy, scientists aim to work it into red tide models. Few have done so successfully for coastal algal blooms, but Dr. Ming Li, a co-principal investigator on this project and UMCES Professor, led successful modeling efforts with another species of mixotrophic algae in Chesapeake Bay. "We plan to extend the mixotrophic model to *K. brevis* because the West Florida Shelf has low nitrate (a nutrient source) concentration and *K. brevis* has been shown to feed on *Synechococcus* as an alternative nutrition acquisition strategy."

This is one of many cutting-edge efforts that may lead to better red tide models and predictions through the Mote-led project. Meanwhile, partners at NYU and Bigelow are particularly focused on the bacteria and viruses that can help or harm *K. brevis*. Some of these microbes can terminate red tide cultures in the lab, and scientists are just scratching the surface of what this might mean for blooms in the Gulf. ■

Left: Dr. Pat Glibert of UMCES (front left), project leader Dr. Cynthia Heil of Mote (front right) and other partners in the NOAA ECOHAB-supported project on the Florida Institute of Oceanography's Research Vessel *Weatherbird II.*

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WHAT THE FUTURE HOLDS

With success in this project, Mote and partners aim to:

Better anticipate red tide impacts.
This would help communities and industries better prepare. For example, government agencies might heed early warnings by setting aside funding for fish cleanup.

Support safe, effective red tide mitigation.
For example, by helping reveal when blooms are susceptible to mitigation tools, and what impacts mitigation will have. Mitigation science is led by the Mote-FWC Florida Red Tide Mitigation & Technology Development Initiative.

Address key questions our communities are asking. For example: How long a bloom might last, how hurricanes, climate change and releases of land-based nutrients affect blooms, and more.