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BIGELOW LABORATORY FOR OCEAN SCIENCES / WINTER 2025

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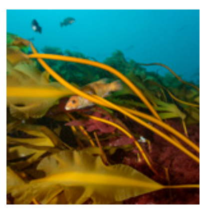

ON THE COVER

A new study led by Senior Research Scientist Doug Rasher provides the first in-depth census of Maine's kelp forests in almost 20 years, telling a complex tale of dramatic declines, significant regional variation, and surprising resilience. Rasher and other Bigelow Laboratory scientists are helping unravel the complex impacts of climate change on the Gulf of Maine and the communities that depend on it. Learn more on page 13.

Photo: Brian Skerry

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Message from the President

Perhaps no other microbe better captures the mystery of the ocean than viruses. Millions, even billions, can exist in a drop of seawater, but there are many unanswered questions about the vital role they play in keeping our oceans — and planet — healthy.

Through a combination of technological advancements over the last 50 years, along with the expertise of our incredible scientists, we're making real headway on this and other difficult ocean questions (see page 2). In these elusive answers lies the information we need to understand and care for our planet — and unlock revolutionary solutions to the challenges our society faces.

The need for this work has never been more urgent.

I have been inspired watching the rapid progress being made on construction of our new center for ocean education and innovation. This vital expansion of our state-of-the-art laboratory can't be completed soon enough. It is an essential component of the vision we have for our science over the next 50 years, and it will provide the infrastructure we need to build on our discoveries and create solutions the world desperately needs.

This connection between our fundamental science and real-world solutions is epitomized by our new Maine Algal Research Infrastructure and Accelerator, which launched this fall with the help of a $7 million grant from the National Science Foundation (see page 8). Leveraging our world-class algae collection and deep knowledge, this robust network of partners across the state will catalyze global solutions and boost Maine's economy with marketable products.

Through these efforts and more, we're bringing all our resources to bear on the greatest challenges our society faces and the abundant opportunities we find in the ocean to address them. And we couldn't do it without your help.

Our next 50 years of discoveries, solutions, and inspiration begin now — and they begin with you! As we enter this new era, please consider supporting our work to outpace the challenges and create the opportunities needed for our planet and society to thrive. With your help, I know we will succeed!

Deborah A. Bronk

DEBORAH A. BRONK, Ph.D.

CONTENTS

RESEARCH TECHNICIAN HANNAH STERLING collects water samples as part of a region-wide effort to monitor levels and track sources of PFAS pollutants into Casco Bay. Learn more on page 15.

Photo: Christoph Aeppli

Viruses are the most abundant biological entity in the ocean. Yet scientists are only just beginning to unravel the full story of how marine viruses work, what role they play in the ecosystem, and how their interactions with other microbes shape marine evolution in real time. Bigelow Laboratory is helping advance that work with new research and tools to illuminate one of the ocean's great mysteries.

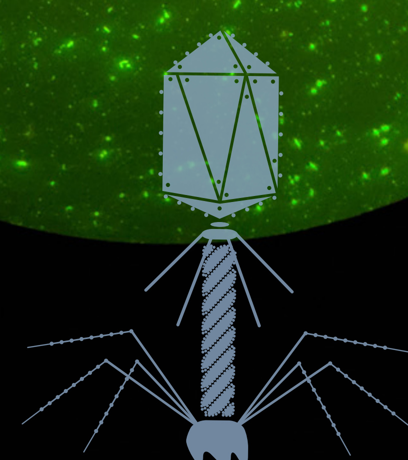
OCEAN ENIGMA

Astronomers estimate that there are an unfathomable 200 billion trillion stars in the observable universe. But that number pales in comparison to the number of viruses found just in Earth's oceans — by as much as 10 million times.

Viruses — tiny, organic, but not-quite-living genetic elements — are considered the most abundant biological entity on the planet. A single milliliter of water can hold as much as a million, or even a billion, individual viruses, each of which plays an essential role in the ecology and evolution of microbial life.

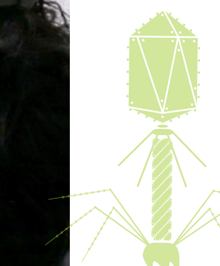
Despite their importance, though, viruses are still an enigma, and scientists are only beginning to understand the profound influence they have on the cycling of energy and nutrients around the ocean. Bigelow Laboratory researchers are helping drive that work forward, answering fundamental questions about viruses' impact on the marine ecosystem and developing the cutting-edge tools needed to study them.

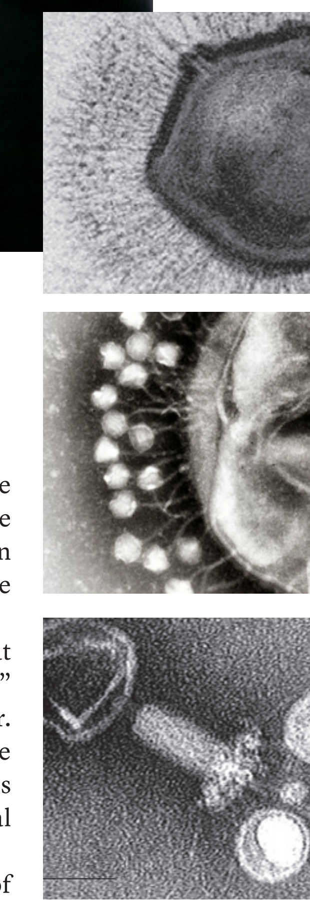
"Viruses are absolutely critical. They're the lubricant of the oceanic engine because of their impacts on biogeochemistry, evolution, and physiology," said Senior Research Scientist Joaquín Martínez Martínez. "You can swim in the ocean 'viral soup' without any danger to you. But the impact of viruses goes beyond illness, and it's more global and more important than we ever thought."



A MICROSCOPY IMAGE at 600 times magnification, shows plankton (the bright green dots) alongside more numerous and smaller marine viruses (the faint, smaller green dots) in a water sample from West Boothbay Harbor.

Photo: Julia Brown





ABOVE J.J. Custer, a University of New England student and participant in the Bigelow Laboratory Sea Change Semester program, combines seawater enriched with viruses and a culture of *Karenia brevis* to study the impacts of viruses on harmful algal blooms. **RIGHT** Microscopy images show several different kinds of marine viruses.

THE MINISCULE DRIVERS OF THE OCEAN ENGINE

Though microorganisms were discovered as early as the 1600s, it took another 200 years until viruses were uncovered. By employing a filter fine enough to remove bacteria, scientists realized there was something else, even smaller, in their samples making people sick. It wasn't until the 1930s that scientists produced the first image of a virus.

"Initially humans only cared about what could cause disease, either to us or the plants and animals we depend on. We couldn't imagine that there were viruses everywhere, much less floating around the ocean," Martínez said. "When I began my Ph.D. in 2001, we were still at the point of just trying to understand basic things like how abundant marine viruses are and what they're even capable of."

It turns out they're capable of quite a lot.

Every day, phages — viruses that infect bacteria and are the most common type — are estimated to kill upwards of 20 percent of the world's bacteria. But the impact of viruses goes far beyond mortality.

In the process of infecting a host, viruses can leave behind bits of their own DNA and hijack pieces of their host's DNA, taking on novel genes and pathways that allow them to infect and manipulate new hosts. In this way, viruses influence the evolution of marine life in real time. In some cases, viruses can also cause persistent infections where they integrate themselves so thoroughly into the host for an extended time that the host cell's existence becomes centered largely on the virus's needs. In those cases, traces of the virus can even persist in the next generation of the host cell, altering the evolutionary fate of that microbe.

"There's probably a specific virus that can infect every kind of living organism," said Postdoctoral Scientist Anne Booker. "That means how organisms simply live their lives and shape their environment is probably influenced at all times by viral activity."

Viruses also help control the cycling of nutrients and energy in the ocean. Some infected algae, for example, have enhanced photosynthesis, increasing the amount of carbon dioxide they can pull out of the atmosphere. But other infected species appear to stop photosynthesizing entirely.

Meanwhile, viruses can also disrupt the flow of energy up the food chain. When a virus kills a microbe, the host cell bursts open. All the nutrients and organic matter within dissolve back into the surrounding water rather than moving up the chain to larger life forms, a process scientists call the "viral shunt." There's also evidence that some organisms feed directly on viruses — Martínez describes them as "little packages of nutrients" — which itself can alter the cycling of nutrients like carbon and nitrogen.

Photos, clockwise from top left: Leah Campbell; E. Ghigo, J. Kartenbeck, P. Lien, L. Pelkmans, C. Capo, J.L. Mege, and D. Raoult; Graham Beards; M.B. Sullivan, M.L. Coleman, P. Weigele, F. Rohwer, and S.W. Chisholm

LEFT Research Scientist Julia Brown examines data while aboard a cruise studying viral and microbial communities in an oxygen minimum zone in the Pacific Ocean. **RIGHT** A bloom of the harmful algae *Karenia brevis* is visible off the coast of Sarasota, Florida, in August 2018.

'The impact of viruses goes beyond illness, and it's more global and more important than we ever thought.'

UNCOVERING THE HIDDEN WORLD OF VIRUSES

Bigelow Laboratory scientists are working to tease out these complicated processes and influences.

Research Scientist Julia Brown, for example, is doing essential research on viral communities in parts of the ocean where oxygen levels are unusually low. These oxygen minimum zones — some of which are naturally occurring and others a result of human activity — play an important role in global nutrient cycles and are expected to grow with warming temperatures.

Scientists have suggested that there are relatively fewer free-floating viruses in these areas compared to other parts of the ocean, hypothesizing that more viruses are locked up in persistent infections. Even so, they're still influencing the behavior and life cycles of their microbial hosts. Brown is trying to understand what that relationship looks like and how it's shaped by the lack of oxygen.

Brown and her collaborators at Woods Hole Oceanographic Institution have visited two different oxygen minimum zones in the Pacific, spending several weeks at each site, collecting some of the most complete data to date on the viral and microbial communities there.

"The thing about viruses is that they're kind of meaningless without the context of who they're infecting," Brown said. "You get a lot more insight into the role of viruses in the ecosystem with these kinds of projects where you can link viruses to their hosts."

Martínez and Booker are also working to tease apart host-virus interactions in a new, complex environment: a harmful algae bloom. They're examining the viruses that infect *Karenia brevis*, a species of algae that routinely produces large, dangerous, and economically disastrous "red tides" in the Gulf of Mexico.

"There's been a lot of information on how temperature and nutrient runoff affect these blooms, but no one really knows much about the microbial community," Booker said. "We're trying to uncover this additional layer to the story of how these blooms work."

As part of a multi-institutional team, the researchers are answering fundamental questions about which viruses are infecting *Karenia* and at what rate. But they are also working on a more applied question. If a virus can kill a *Karenia* cell, is it possible that a lot of viruses could kill enough *Karenia* to stop a harmful bloom?

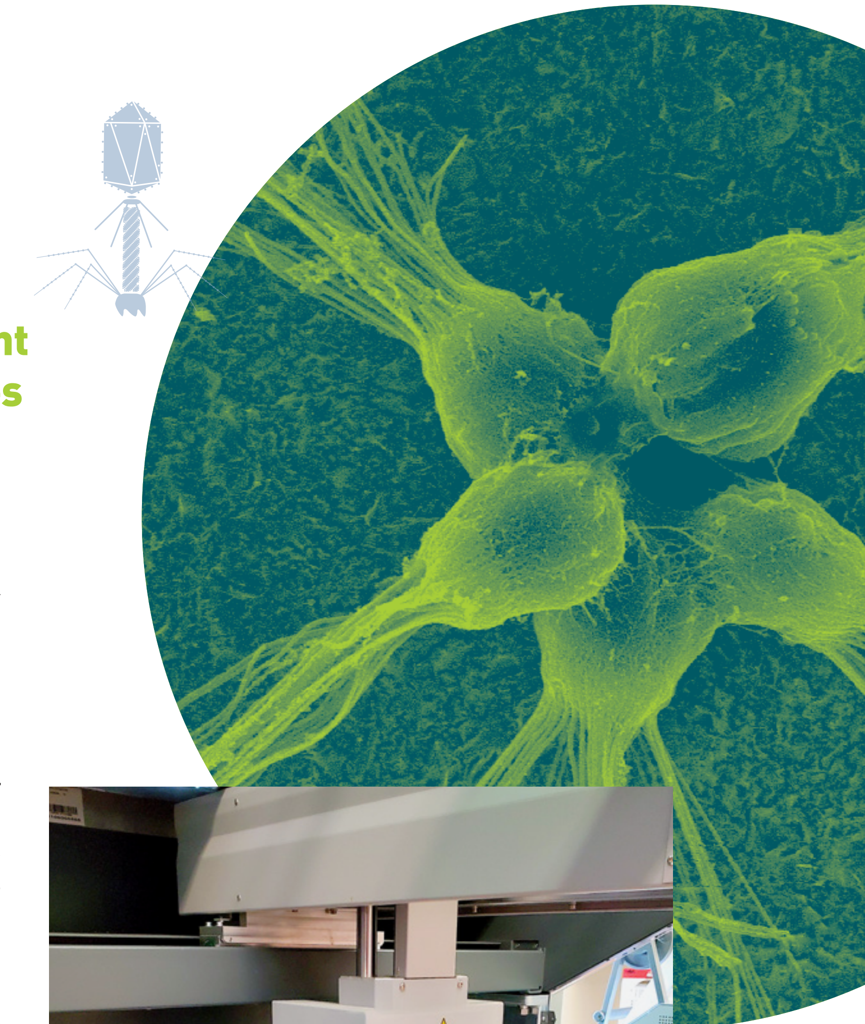
The team recently took a sample of seawater from a *Karenia* bloom in the Gulf of Mexico and filtered out all of the larger organisms, leaving just viruses behind. They then added that seawater to a flask full of *Karenia* cells, taken from Bigelow Laboratory's National Center for Marine Algae and Microbiota. Within a few weeks, many of the algae cells died.

Booker and Martínez are now mapping out all the DNA in the sample to characterize the kinds of viruses killing the *Karenia* cells. Meanwhile, collaborators at NYU Abu Dhabi are using a similar method to look at bacteria to understand how the algae, bacteria, and virus interact, and what impact that has on the fate of the harmful blooms.

The story, it turns out, is even more complicated than they imagined.

In the bloom seawater, they found at least six types of giant viruses, all of which appear to infect *Karenia* while competing with each other. They also identified several kinds of phages, some of which may indirectly harm the algae by infecting "good" bacteria the algae need and other phages that may protect the algae by killing off harmful, "algicidal" bacteria. And, on top of it all, the researchers found preliminary evidence of several smaller viruses in the sample that could be attacking the giant viruses.

Photos, left to right: Julia Huggins, Vince Lovko



'How organisms simply live their lives and shape their environment is probably influenced at all times by viral activity.'

Together these complex interactions appear to create an unexpected balance in the ecosystem that allows the bloom to linger.

The research will continue for another year. Booker says they've isolated several of the viruses in the sample and plan to sequence their individual DNA. They're also continuing fieldwork in the Gulf of Mexico and lab experiments to unravel the mechanisms and consequences of these microbial interactions. The hope is to get enough data to improve the models that estimate how long a bloom will last. Even if they can't use viruses to end blooms, having models that accurately account for viral activity will help managers better respond to and plan for them.

"Unfortunately, there is no simple answer," Booker said. "There's such a complex microbial web, and there are many complicating environmental factors, but if we keep asking the right questions, we may get solutions for the future."

NEW TOOLS FOR VIRAL RESEARCH

What makes research projects like these difficult isn't just the lack of prior knowledge to build off. It's also just that viruses are extremely hard to study.

"Viruses are so diverse — probably more diverse that any other biological thing — and they encode so many genes that haven't been identified," Brown said. "They're also just very small, so there are limited ways of seeing and detecting them."

For example, on Brown's recent oxygen minimum cruises, processing a single sample of seawater took upwards of 12 hours. Because viral genomes are so small, she had to collect a lot of water to get enough genetic material to detect viral DNA. She also had to filter and strain her samples repeatedly to concentrate them and remove any larger organisms. To produce each 300-milliliter sample for her research, she had to collect 300 times more raw seawater.

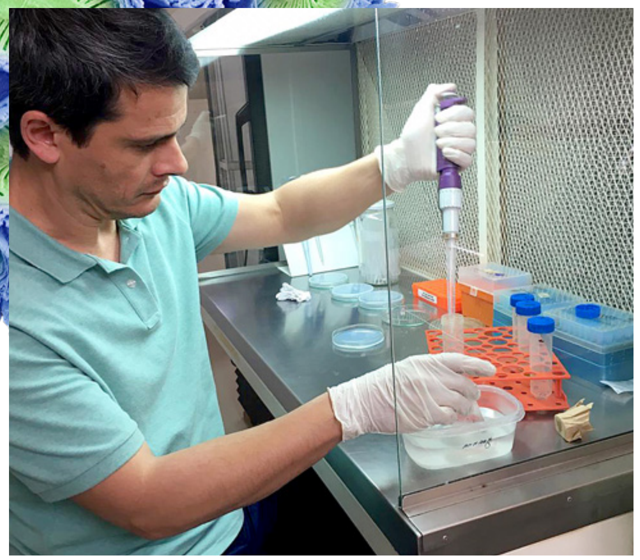
Viruses are also exceptionally "micro-diverse" meaning that no two individuals are the same. Each contains endless little mutations and hijacked bits of DNA, reflecting the particular infection history of that individual and all its evolutionary consequences.

Advanced technology adapted for virology over the last 20 to 30 years has created new possibilities but also new challenges.

Metagenomic sequencing, which has been applied to viruses since the early 2000s, for example, enables scientists to sequence all the DNA in a water sample and get some information on everything in it. But that approach biases results towards whatever organism has the most

TOP A choanoflagellate is a microscopic organism that Bigelow Laboratory scientists have shown can consume viruses directly as food. **BOTTOM** Robotic equipment processes samples at the Single Cell Genomics Center, which sorts and analyzes the genetic information of individual cells and viruses.

Photos, top to bottom: Mark Dayel, Rachel Kaplan



BEHIND A microscopy image shows a coccolithophore, *Pleurochrysis carterae*, that is persistently infected by three viruses that do not kill it. **ABOVE** Senior Research Scientist Joaquín Martínez Martínez examines viral samples in the lab.

DNA, not what's necessarily the most abundant or important. And because viruses have particularly small and diverse genomes, it can also be hard to assemble the different chunks of DNA. It's like putting together multiple puzzles at once that all look similar — and are all missing pieces.

Single cell genomics, advanced by Bigelow Laboratory's Single Cell Genomics Center for the last 15 years, has helped address some of those problems by enabling scientists to isolate and sequence virus genomes individually. That fixes the multiple puzzle issue, and the use of robots through much of the process minimizes the risks of contamination.

"With metagenomics, it can be hard to assemble a complete genome because of the huge diversity of viruses," said Senior Research Scientist Ramunas Stepanauskas, director of SCGC. "That's why the approach of sequencing individual viral particles is so powerful because we don't have to rely on so many assumptions to stitch together the bits of DNA."

But even single cell genomics has its limits. A scientist needs to know what kinds of viruses they're targeting and have tools for isolating those individuals. The first step of SCGC's workflow, for example, is to use flow cytometry to sort the sample into individual particles, but because of their miniscule size, viruses often get lost in the process.

"The tools are improving all the time, but we need to adapt them to apply to viruses, and there's no one tool that works for all different types of viruses in all different environments," Martínez said. "You need a suite of complementary tools to look at the same thing from different angles."

'I used to say microbes rule the world, but it seems more and more that viruses dictate most of what's going on, and we had no idea until relatively recently.'

These challenges are inspiring Bigelow Laboratory scientists to develop new tools.

Brown and Stepanauskas, with Postdoctoral Fellow Alaina Weinheimer, have been working to design a method — called Environment Microcompartment Genomics — that can give scientists the same, fine-grained detail they can get from single cell genomics approaches but at a much larger scale.

"This new approach allows us to work with pretty much any size of virus, and we can process a much larger number of them without significantly increasing cost," Stepanauskas said. "We'd have to fill a whole wing of our laboratory with equipment to increase the capacity of our current techniques to the same level."

In the new method, an infinitesimally small amount of seawater, containing a single cell or particle, is stored in a tiny capsule. The DNA in each individual capsule is given a unique barcode so every segment that is sequenced can be traced back to the individual it came from. Because the approach skips the initial flow cytometry step, scientists aren't able to get additional information about each particle, like its size. The benefit, though, is that they can process many more — and much smaller — viruses than ever before. It will also make it easier to detect viruses from sediment or soil without them getting missed or confused for other particles.

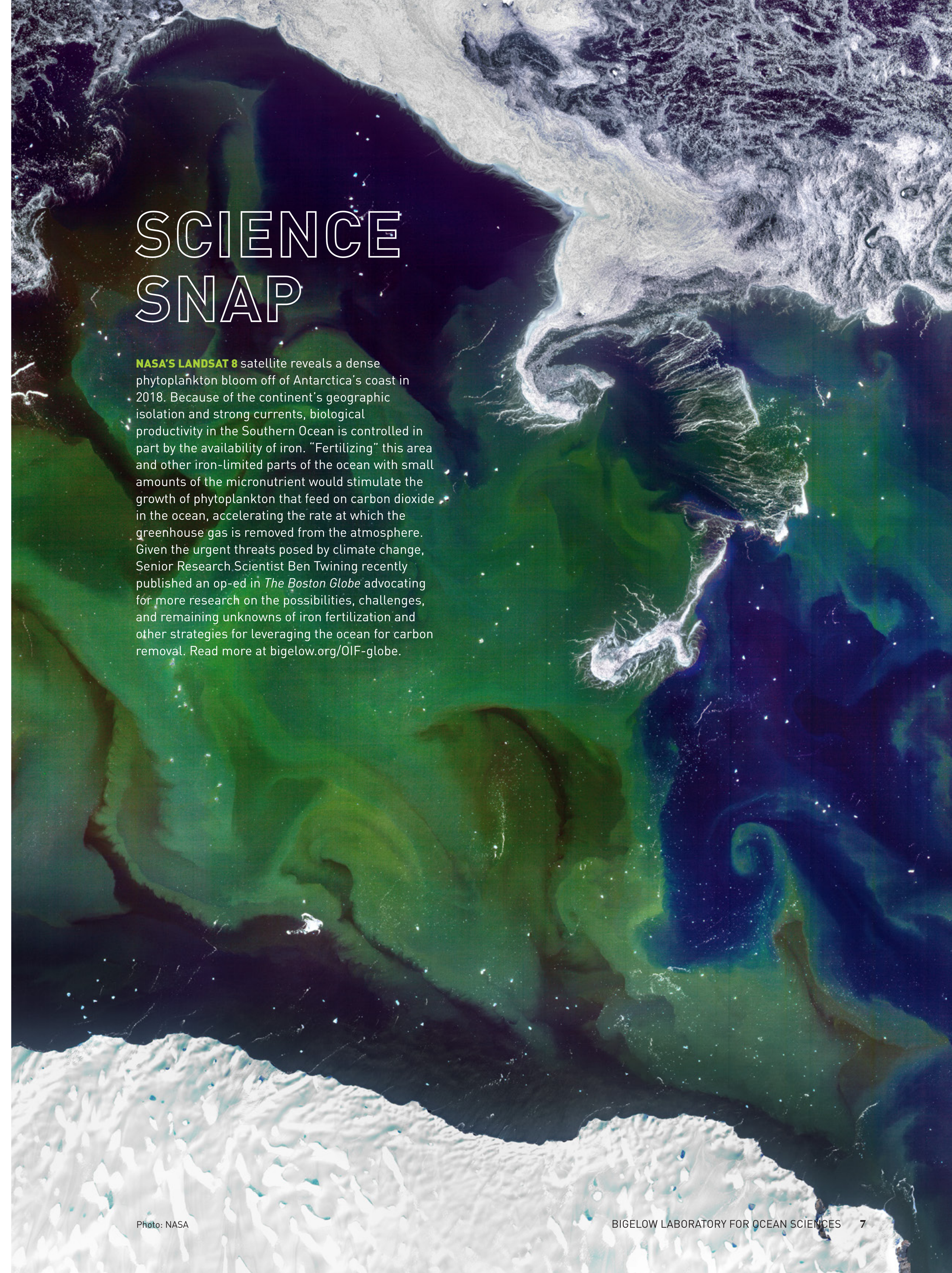
With the capsule method, Brown said they've gotten some of the highest quality viral genome sequences she's seen recovered from an environmental sample. Stepanauskas added that the diversity of viruses they're seeing so far is "mind boggling." The team hopes to publish their first results in the coming months.

"We need these kinds of technologies to start understanding how viruses evolve," Stepanauskas said. "That's important for the ocean, but eventually it's also going to inform everything from medicine to the agricultural field."

For better or worse, all the scientists point out, it's not hard to make the case for why viral research matters post-Covid.

"I used to say microbes rule the world, but it seems more and more that viruses dictate most of what's going on, and we had no idea until relatively recently," Booker said. "Anytime you can answer one small question about viral interactions, it really moves the whole field forward."

Photos, left to right: Mike Allen, Tracey Beacham, and Steve Gschmeissner; Rachel Kaplan



SCIENCE SNAP

NASA'S LANDSAT 8 satellite reveals a dense phytoplankton bloom off of Antarctica's coast in 2018. Because of the continent's geographic isolation and strong currents, biological productivity in the Southern Ocean is controlled in part by the availability of iron. "Fertilizing" this area and other iron-limited parts of the ocean with small amounts of the micronutrient would stimulate the growth of phytoplankton that feed on carbon dioxide in the ocean, accelerating the rate at which the greenhouse gas is removed from the atmosphere. Given the urgent threats posed by climate change, Senior Research Scientist Ben Twining recently published an op-ed in *The Boston Globe* advocating for more research on the possibilities, challenges, and remaining unknowns of iron fertilization and other strategies for leveraging the ocean for carbon removal. Read more at bigelow.org/OIF-globe.

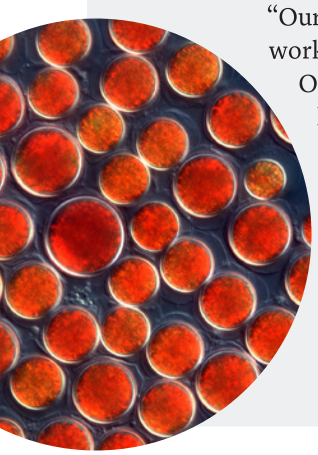
Photo: NASA

FROM IDEA TO INNOVATION

Scientists at Bigelow Laboratory know there are nearly limitless possibilities hidden in the world of algae, and they have bold ideas to tap into that potential for drug discovery, food security, climate change mitigation, and many more applications. New investments and partnerships are helping create an "innovation ecosystem" to help translate those discoveries into products and solutions for the future.

For 50 years, Bigelow Laboratory has used fundamental science to illuminate the foundation of global ocean health. Increasingly, the institute's researchers have also strived to use their discoveries to improve the future for all life. In a rapidly changing world — with growing threats from climate change, fisheries collapse, declining federal scientific funding, and myriad other sources — those interconnected aims are more important than ever.

"Our main driving question is how does the world work," said Vice President for Research Beth Orcutt. "That foundational understanding can lead to new innovative ideas that are really going to make a difference."



HAEMATOCOCCUS is a type of algae grown commercially as a source of astaxanthin, a valuable nutrient for the aquaculture and nutraceutical industries.

That approach is exemplified by Bigelow Laboratory's new Maine Algal Research Infrastructure and Accelerator project within the Center for Algal Innovation. MARIA, funded by a $7 million award from the National Science Foundation, will strengthen biological research infrastructure, create education and workforce development opportunities, and bring together the interdisciplinary teams needed to get algae-based solutions to market. These activities will position Maine as a leader in the emerging blue economy and help achieve goals of the Maine Innovation Economy Action Plan, which specifically calls out growth opportunities for algae-based businesses.

Bigelow Laboratory and the MDI Biological Laboratory, the scientific partners of MARIA, are launching the project by building core knowledge about the compounds that algae produce and their potential applications in aquaculture, agriculture, energy, and medicine. To do so, they are mining the vast biological resources of the National Center for Marine Algae and Microbiota. Housed at Bigelow Laboratory since 1980, NCMA contains one of the most diverse collections of marine algae in the world.

BIGELOW LABORATORY SCIENTISTS and other MARIA partners engage in speaker series, trade shows, and community workshops to share information, attract new collaborators, and brainstorm bold ideas for how to leverage the potential of algae.

'Our main driving question is how does the world work. That foundational understanding can lead to new innovative ideas that are really going to make a difference.'

Critically, about two-thirds of the collection's almost 4,000 strains are microalgae. While most existing businesses in Maine focus on macroalgae species like kelp, microalgae's incredible genetic diversity offers vast untapped potential.

"The first year of the project is focused on generating data — characterizing the algae we have and what those strains can do," said Senior Research Scientist Manoj Kamalanathan, one of the project's principal investigators. "We need that information to drive business ideas."

Kamalanathan is exploring the possibilities of using algae to produce hydrogen, a clean source of fuel. With a database like what they will create through MARIA, he'll be able to test many types of algae to find the strains that can produce hydrogen most efficiently and at scale.

MARIA will also provide kickstarter funding for scientists who want to tap into its intellectual resources. Through a competitive selection process, researchers will get support for early-stage, creative ideas that could potentially solve real problems.

This early support is essential and often hard to come by. For example, Senior Research Scientist Mike Lomas, the other principal investigator of the project, is working with MDI Biological Laboratory to scan NCMA's collection for algae that produce anti-inflammatory compounds. Together, the two institutions have the expertise and capacity to do the work, and, if selected for funding, the research would get the boost it needs to move forward.

"The project is proof," Lomas said, "that there are these partnerships and ideas ready to go that can benefit from the investments, knowledge, and infrastructure MARIA will provide."

But MARIA isn't just about research. Several of the project partners are in the business-development space. Maine Technology Institute, Gulf of Maine Ventures, and Maine Center for Entrepreneurs work to support and stimulate entrepreneurship and can help turn ideas into marketable products. Meanwhile, the other partners are educational institutions, including Southern Maine Community College, University of New England, and Colby College, that can encourage entrepreneurism in students and help train a skilled workforce.

Using that comprehensive expertise, the team will develop a training program targeting mid-career professionals and then match those students to the businesses that need them — helping keep good jobs and skilled

Photos, top to bottom: Greta Rybus, Pete Countway

Photos, clockwise from top left: Tim Greenway, Tim Greenway, Leah Campbell, Mike Lomas, Tim Greenway, Leah Campbell

‘I feel so fortunate to have these incredible resources from teams across the institution to lean on — heavily — for developing solution-oriented projects.’

LIVE COW HERDS and experimental "bottle herds" enable the Coast-Cow-Consumer team to conduct multidisciplinary studies on the potential of algae-based feed supplements to reduce methane emissions by cattle.

workers in Maine.

“These network nodes existed, but the impediment was getting everyone meaningfully connected,” Lomas said. “In Maine, we have all the strengths we need to create an effective innovation ecosystem, and now we have the infrastructure to bring them together.”

As part of that effort, Bigelow Laboratory has actively engaged in outreach to create new connections and inspire exciting ideas. In September, Bigelow Laboratory and Gulf of Maine Research Institute co-hosted an event where Orcutt and Lomas, alongside GMRI’s Chief Ventures Officer Blaine Grimes, discussed opportunities to harness microalgae in biotech. And earlier that month, Northeastern University’s Roux Institute hosted an event in Portland highlighting NCMA in a hands-on brainstorming session on algae-based solutions.

At the Algal Biomass Summit trade show in Houston this October, the NCMA team also showcased information about MARIA to start enticing outside scientists, investors, and businesses to come to Maine. And in November, Bigelow Laboratory co-sponsored the Blue Venture Investment Summit in Portland to build new relationships and start exploring what Bigelow Laboratory can offer to “blue technology” investors.

This approach builds on a model that the institute has been refining for several years with the Coast-Cow-Consumer project to address methane emissions from livestock. Like MARIA, C3 has grown from a spark of an idea to a multi-institutional, multidisciplinary effort to use algae to solve real-world problems.

The C3 team is developing an algae-based additive for cattle feed that could alter cows’ digestive system in a way that would reduce methane emissions from their burps. Though there are strains of macroalgae known to contain compounds that do that, the researchers have been screening species to find the most promising microalgal strains as well. From there they can create a product that can be produced at a large scale — ideally supporting a local aquaculture industry in the process — that is healthy for cows, generates return on investment for farmers, and benefits the environment.

They’ve built a network of what Senior Research Scientist Nichole Price calls a “unique and exciting mix of experts” in diverse fields such as algal physiology, ecotoxicology, socioeconomics, carbon accounting, and animal health. As with MARIA, partners that can communicate the science, and business development entities that can untangle regulatory and market barriers, are also central to the team.

Solutions-focused collaborations like MARIA and C3 draw on Bigelow Laboratory’s expertise in cutting-edge science and require the project teams to seek out new, interdisciplinary partners. But, Orcutt said, that exemplifies the collaborative spirit that’s defined the institute from day one and characterizes the ways its interdisciplinary scientists broadly share their work.

“Our analytical capabilities and our repository of algae are unparalleled on a global scale,” Price said. “I feel so fortunate to have these incredible resources from teams across the institution to lean on — heavily — for developing solution-oriented projects.”

Cooperative, curious science has inspired Bigelow Laboratory researchers for 50 years, and it’s continuing to inspire the bold, applied projects that will be a growing — and complementary — focus to its fundamental research in the coming decades.

“We’ve got innovation potential here, both in our scientists and the assets we have as a lab,” Orcutt said. “Thinking out to the next 50 years, I believe we can make a real difference in the world by investing to unlock that full potential.”

Photos, top to bottom: Colby College, Colby College, Brittney Honisch

TRIBUTE

Louis E. “Sandy” Sage

APRIL 25, 1940 – SEPTEMBER 26, 2024

A FORMER EXECUTIVE DIRECTOR who oversaw our organization during a pivotal decade, Louis “Sandy” Sage, passed away earlier this fall after a hard-fought battle with Alzheimer’s.

Sandy led the organization from 1996 to 2006, during which time he helped bring Bigelow Laboratory into its modern era and the vanguard of international ocean research. Under his leadership, our staff and board built the foundation on which Bigelow Laboratory could grow into the world-class organization it is today.

With a bold vision for the future, Sandy secured the land that our laboratory stands on in East Boothbay, and he was there in 2010 when we broke ground on the state-of-the-art facility we now occupy. The major laboratory expansion underway today on our campus serves as a bittersweet reminder of Sandy’s leadership legacy.

His scientific legacy, however, expands far beyond Maine. With a doctorate in marine biology and over 20 years of service at what is now the Academy of Natural Sciences at Drexel University, Sandy also made important contributions to the field of estuarine science and the preservation of the Chesapeake Bay watershed.

Sandy is survived by his wife of 41 years, Honor Fox Sage. Both Honor and Sandy are remembered fondly by many longstanding staff and donors for their leadership — and their excellent holiday parties. As we step into the next 50 years of Bigelow Laboratory, he will be remembered as an instrumental part of our history and our community.

SCIENCE SNAP

MARINE EDUCATOR AISLYN KEYES (center) teaches Colby College geology students oceanographic field methods aboard the R/V *Bowditch*. The boat was acquired in 2022 to make these kinds of hands-on learning opportunities possible for internal education programs, as well as external student groups, while also enabling new and expanded research in the Gulf of Maine. Around the same time, Keyes was hired to help enhance Bigelow Laboratory's education programs as part of a large investment into the new center for ocean education and innovation.

Photo: Bess Koffman

CURRENTS

Photo: WGBH Educational Foundation, Chun-Wei Yi

Photo: Duane Moser

New Technique Illuminates Hidden Life of Microbes

In recent years, researchers have made significant leaps in sequencing the genetic information of single cells. However, linking those genes with the specific function and behavior of individual microbes remains one of the great challenges in microbiology. It's also essential for uncovering microbes' roles in global processes like the carbon cycle.

A team of scientists led by researchers at Bigelow Laboratory and the Desert Research Institute have been developing an innovative method to fill that gap as part of the multi-institution, NSF-funded "Genomes to Phenomes" project. This year, they tested the method on microbes living without oxygen deep below Earth's surface. They discovered that one species of sulfate-consuming bacterium was the most abundant and active organism in a groundwater aquifer beneath Death Valley. Those findings highlight how powerful this approach is for teasing apart the vital contributions of microbes in extreme environments. The team is continuing to refine the method for application to wide-ranging environments and microbial processes.

MEDIA SHOWCASES THE CHANGING GULF OF MAINE

Since the founding of Bigelow Laboratory, its researchers have applied scientific lessons learned from around the world to better understand and leverage the Gulf of Maine's vibrant and economically important ecosystem. Some of that critical work was showcased this summer with high-profile, national media coverage.

A cover story in *National Geographic* and a three-part *NOVA* documentary looked at the dramatic changes happening in the Gulf, highlighting the efforts of senior research scientists David Fields and Doug Rasher to understand how the marine food web is adapting to those shifts. Rasher also received widespread coverage for leading a team that recently published findings from their comprehensive survey of the health of Maine's kelp forests — the first in over 20 years. Growing interest in these stories emphasizes the immense threats facing the Gulf and the communities that depend on it, as well as the discoveries and solutions of Bigelow Laboratory scientists that are helping chart better paths forward.

Maine Leaders Launch New Collaborative

Bigelow Laboratory President and CEO Deborah Bronk recently drove the launch of a new collaboration that is helping create a more unified and resilient ocean science sector in Maine. Member organizations of the Maine Marine Science Consortium represent different industries from across the state, all united around similar goals for advancing ocean science, education, and innovation.

Almost 50 leaders from 19 organizations across the state gathered at Bigelow Laboratory early this year to launch the new partnership. The initial meeting enabled attendees to discuss common challenges and opportunities and brainstorm priority areas for collaboration. This summer, Bigelow Laboratory hosted the first official social event of the consortium to help foster collaboration among staff at different organizations. Several meetings and social gatherings have since helped forge stronger connections between organizations and inspire new partnerships on a diverse array of ocean issues.

Initiative Advances Community-Led Science

Partnerships with community groups, tribal organizations, and local governments bring in-depth knowledge, data, and long-term engagement that Bigelow Laboratory can both enhance and benefit from. The Water Health and Humans Initiative, directed by Senior Research Scientist Rachel Sipler, has been building partnerships with communities across Maine to bring their expertise to bear on critical environmental health issues. Recently, the team has developed several collaborative projects with the Wabanaki Nations around food systems, water contamination, and more via an EPA-funded grant led by Chris Johnson at the Sipayik Environmental Department alongside Sipler and senior research scientists Christoph Aeppli and Ben Twining.

This summer, Sipler worked with Wabanaki Public Health and Wellness to launch a new student exchange program for WPHW and Bigelow Laboratory interns. The program kicked off with a visit by WPHW interns for several days of peer-to-peer learning, cultural exchange, and scientific exploration. Meanwhile, Sipler and her team have continued a project that began last year with the Sipayik Environmental Department to monitor fish populations and water quality in response to dam removal on the Skutik River.

Photo: Collin Sheehan

CAFÉ SCI KICKS OFF 50TH ANNIVERSARY

Bigelow Laboratory's annual Café Sci series is a fun, free way for community members to engage with ocean researchers on critical issues and groundbreaking science. This year, the institute organized a special edition of the series that served as the launch of 50th anniversary celebrations. In a fitting call back, talks took place at the Boothbay Harbor Opera House, where Café Sci was previously held for many years, due to the expansion underway at the Bigelow Laboratory campus.

After kicking off with a look back at how Bigelow Laboratory evolved — and ahead to how it plans to extend its impact in the coming decades — the series covered some of the key innovations the institute has advanced since its founding in 1974. From flow cytometry to satellite oceanography and single cell genomics, presenters shared about each innovation's importance and what they may enable over the next 50 years.

Scientists Learn to Listen to Algae

Photo: John Burns

A team of scientists from Bigelow Laboratory, led by Senior Research Scientist John Burns, recently showed that glaucophytes, a small group of single-celled algae, have the ability to release chemical hormones to communicate stress. The discovery suggests that the capacity for using chemical cues in this way may not be unique to complex organisms like plants, as once thought, but rather evolved further back on the tree of life.

Illuminating how cell communication works in different lineages provides important insight on how these abilities developed and changed over time. Finding these kinds of evolutionary commonalities will also help scientists understand how algae, and eventually plants, emerged and evolved. The team is hoping to continue the work by looking at how glaucophytes change their behavior in response to these chemical cues, whether other species of algae have the same ability, and whether the chemicals involved in these processes could have potential commercial applications.

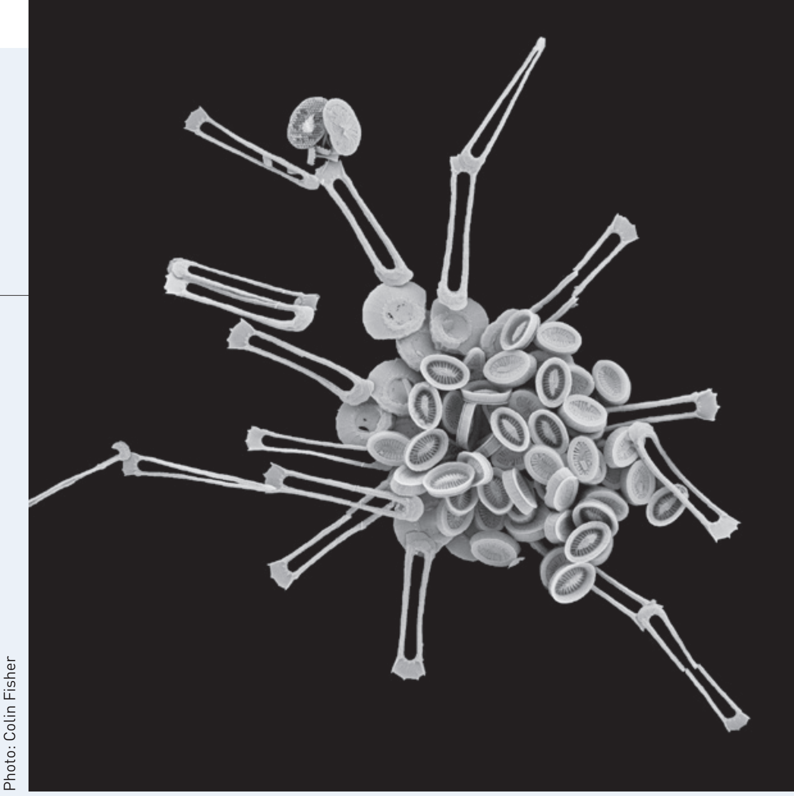


Photo: Colin Fisher

Microbes Adapt Feeding Habits to Changing Conditions

Mixotrophs are organisms that can shift their feeding habits as needed from photosynthesis to consuming prey or absorbing organic nutrients directly — and scientists are learning they're far more common in the ocean than once thought. A team of researchers led by Senior Research Scientist Karen Stamieszkin recently provided the first basin-level view of how the distribution of mixotrophs has varied spatially and seasonally across the North Atlantic over the past 60 years.

The findings show that the proportion of organisms capable of mixotrophy has distinctly increased in recent decades, especially when it's warmer or nutrients are less abundant. Understanding these patterns will help scientists better understand the impact of mixotrophy on nutrient cycling and food web dynamics. Because their flexibility appears to make mixotrophs more resilient to unstable conditions, tracking their abundance also provides insight on how the global ocean may respond to change in the future.

Photo: Christoph Aeppli

RESEARCHERS MONITOR PFAS "FOREVER CHEMICALS"

Bigelow Laboratory scientists are providing critical information on the prevalence, movement, and potential impacts of PFAS, so-called forever chemicals, in the marine environment. The institute recently launched new analytical services, certified by the State of Maine and led by Senior Research Scientist Christoph Aeppli, to test for PFAS in water, sediment, soil, and tissue. The services will provide valuable data to stakeholders and give them access to Bigelow Laboratory's broad array of services and specialized knowledge.

Aeppli and his team are leveraging those PFAS capabilities in partnership with the nonprofit, Friends of Casco Bay, to assemble the most complete dataset yet of PFAS levels in the waters of Casco Bay. Last season's monitoring showed widespread occurrence of these chemicals across the region at relatively low levels. The team is continuing to collect data to better understand the primary sources of PFAS into Casco Bay and assess how the August 2024 spill in Brunswick affected this area.

COMMUNITY ENGAGES WITH OCEAN SCIENCE

Photo: Evan Henerberry

This year, Bigelow Laboratory staff launched a casual, monthly speaker series to share fun aspects of ocean science. Spearheaded by a team of postdoctoral scientists and hosted by Footbridge Brewery in Boothbay Harbor, Ocean on Tap provides a space for community building, especially during the quieter off-season, bringing people together around the fascinating world of the ocean.

The event has enabled early-career scientists to practice their communication skills while encouraging them to explore broader areas of interest beyond their day-to-day work. The series has also created new connections between the institute and staff at partner organizations in the area who have presented and helped promote the event. Talks have continued monthly since the launch, covering everything from marine diseases and nutrition to white shark conservation and kelp forest health, with the goal of making it enjoyable and easy for the public to engage with these complex topics.

FIELD NOTES

Panama

SARA SWAMINATHAN, Postdoctoral Scientist

"I like studying fish because they wake up late," my new colleague Matt Leray, a scientist at the Smithsonian Tropical Research Institute, joked as we sipped coffee on the deck of an 80-foot sailboat. A few days prior, a group of scientists and crewmembers, and a member of an Indigenous group that stewards the surrounding waters, had gathered on the ship and embarked from Bocas del Toro, Panama. We sailed to Isla Escudo de Veraguas, where we anchored offshore, waiting for the fish to wake up.

Matt's comment initiated a scuffle, as we were jolted from our reverie and reminded that there was lots of work to do before the fish woke up. Datasheets were attached to dive slates, wetsuits were donned, batteries inserted into cameras, and transect tapes and PVC quadrats tossed onto the dinghies used to navigate to our sites.

This trip was the first assignment in my new role as a postdoctoral scientist with Senior Research Scientist Doug Rasher at Bigelow Laboratory. We were there for a collaborative, NSF-funded project led by Doug that aims to reveal how the feeding preferences of algae-foraging fish, which help maintain the ecological balance of coral reefs, may shift as reefs degrade.

I spent the morning with colleagues from UC Santa Barbara and UT Austin conducting fish behavior surveys, or "fish follows." With a stopwatch and datasheet at the ready, we snorkeled behind herbivorous fish, recording their every move. Were they eating the short, grass-like turf algae that quickly colonizes available substrate? Or were they interested in the taller stands of macroalgae that sway with the current? How many bites did they take before looking around warily for potential predators? As they fed, were they chased off by territorial fish, or did they chase off others themselves? Answering these questions will help us understand the competition and division of resources among different types of herbivorous fish, all unknowingly working together to keep the reef healthy. And illuminating how fish diets shift will help us predict the resilience of these important habitats to climate change globally.

Herbivores are important for maintaining balance in reef ecosystems because they feed on coral's primary competitor: algae. In Panama, we're studying two species of surgeonfish and six species of parrotfish, brightly colored fish named for the resemblance their mouths have to parrots' beaks. Those beak-like mouths are what make them so adept at grazing because some types of algae, like turf algae, can only be removed by scraping away the top layer of rock where the turfs grow.

Each fish follow lasted five minutes, but it felt like an eternity. Fish are fast. One glance away to record data could mean losing the fish completely, as they darted around the reef, quickly feeding and avoiding predators. Meanwhile, some members of our team conducted surveys of the algae and fish communities at our study sites. Others collected samples of fish and their prey for DNA sequencing and isotope analyses that will tell us what exactly they were eating, and ultimately, how good fish are at divvying up resources and keeping algae at bay.

After spending the daylight hours on the water, our team returned to the sailboat where we began dissecting our collections. This part was quite literally an "all-hands-on-deck" operation, with undergraduates and PIs seated side-by-side, separating stomachs from livers and preserving every piece of the fish to get as much information as possible. It was a flurry of activity and languages, as our multinational, multilingual team of scientists worked together to get the job done. The captain, Juan, kept spirits high by spinning an eclectic selection of salsa and bossa nova tracks.

Around 9 p.m., we all sat around a hearty dinner prepared by our incredible cook, Anjio, rehashing the day, laughing, and planning for the next one. It's good that the fish like to sleep in, because they had a way of keeping us up late, and we enjoyed every minute of it.

Photo: Juan Pablo Lozano Peña

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Photo: Pete Countway