2023

# WAVE MAKERS

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# Letter from WHOI President and Director Peter B. de Menocal

**Just three years ago, the 2020 report of the Intergovernmental Panel on Climate Change provided one of the most shocking updates I have heard in my career.** It stated that for Earth's temperature to stay below the 2 degrees C warming threshold, we must devise and implement methods of carbon dioxide removal (CDR). Why? Because humanity has delayed action so long that emissions reduction efforts are no longer enough.

The good news is the ocean is a climate hero. It absorbs more than 90 percent of excess heat rising from greenhouse gas concentration and absorbs 25 percent of our annual carbon emissions. Its potential to remove even more carbon is staggering. If the entire atmospheric carbon dioxide problem to date were mixed into the ocean like a Martini, it would represent just one percent addition to the ocean reservoir.

The even better news is that at Woods Hole Oceanographic Institution, we are actively working on problems like the role of fundamental ocean processes on ocean carbon uptake and storage and developing novel ways to measure and monitor carbon flows throughout the world's ocean.

With our knowledge of the ocean's influence on climate and our Vision 2030 roadmap, the past year has been filled with transformative change and growth. The new vision, combined with your generous unrestricted support, is driving excellence, innovation, and impact in ocean science at a time when the world needs it most.

WHOI scientists are advancing fundamental research, devising novel ideas for mitigating climate change, and engaging with the world to promote collaboration and ocean science literacy. We are also accelerating our efforts to unleash talent needed to tackle today's ocean challenges—and to make WHOI and the field of oceanography a more diverse and welcoming place.

Thanks to unprecedented funding during the quiet phase of a bold capital campaign, WHOI is in an exciting growth mindset. Between 2022 and 2023, we launched highly successful programs to spark scientific innovation, hired more engineers to invent the next generation of ocean science tools, and increased base growth for WHOI research.

Unrestricted giving like yours is the lifeblood of Woods Hole Oceanographic. It enables us to respond nimbly to emerging opportunities and often leverages new funding for great ideas.

In the following pages, you will read about the people and projects that have benefitted from the strategic use of unrestricted funds. As you will see, we are laser-focused on climate and other solutions-based science, including testing promising ocean carbon dioxide removal strategies, and continuing to probe the underpinnings of the biological carbon pump behind the ocean's heroic carbon sequestering abilities.

I am deeply grateful to all of you for your investment in ocean science and your trust in WHOI to deploy your funds for maximum impact. Together, we are taking bold action in the face of alarming environmental change.

Sincerely,

Peter B. de Menocal

On the cover:
A green phytoplankton bloom swirls across a section of the Baltic Sea. (Image by Joshua Stevens and Lauren Dauphin, NASA Earth Observatory, using Landsat data from the U.S. Geological Survey and MODIS data from LANCE/EOSDIS Rapid Response)

# RESEARCH HIGHLIGHTS

# An International Collaboration on Ocean Iron Fertilization

**Every year, humans pump about forty billion tons of carbon dioxide into the atmosphere.** The heat resulting from this greenhouse gas is disrupting planetary systems and reshaping life on Earth as never before. WHOI senior scientist Ken Buesseler and a team of national and international scientists are exploring an ocean solution aimed at reversing this trend. It's a carbon dioxide removal strategy called Ocean Iron Fertilization (OIF) that artificially adds the essential micronutrient iron to seawater to stimulate ocean phytoplankton growth. The phytoplankton convert sunlight, water, and carbon dioxide from the atmosphere into food and oxygen, thus removing substantial amounts of carbon dioxide from the atmosphere. OIF mimics the natural process that occurs when iron in the form of dust from the Sahara or ash from volcanic eruptions is blown onto the ocean's surface.

OIF has the potential to remove vast amounts of carbon dioxide from the atmosphere, but scientists collaborating on it know they must proceed ethically and with caution. Toward that end, Buesseler and others have established Exploring Ocean Iron Solutions (ExOIS)—an international consortium for idea sharing and for testing OIF as a viable climate crisis solution. The group, consisting of 37 universities, private research laboratories, and companies, meets regularly to collaborate on best practices and governance for further study of ocean iron fertilization as a CDR method and to stimulate OIF research activity.

"We are basing our work on recommendations from the recent NASEM and Aspen reports to catalyze individual enabling studies and help organize large international proof-of-concept field and modeling studies," says Buesseler. "We are seizing this opportunity to invest in the knowledge necessary to ensure that we can make scientifically and ethically sound decisions for the future of our planet." ■


Photo courtesy of Sarah Smith, Moss Landing Marine Labs

# Testing a Novel Approach to Carbon Dioxide Removal

**To remove carbon dioxide from the atmosphere, scientists are looking at a technique known as ocean alkalinity enhancement (OAE), which "accelerates the ocean's natural ability to take up carbon dioxide while balancing the ocean's chemistry at the same time," according to WHOI assistant scientist and project lead Adam Subhas.** Supplementing the ocean's already massive natural reservoir of alkalinity, he adds, can result in faster rates of carbon dioxide intake without provoking ocean acidification.

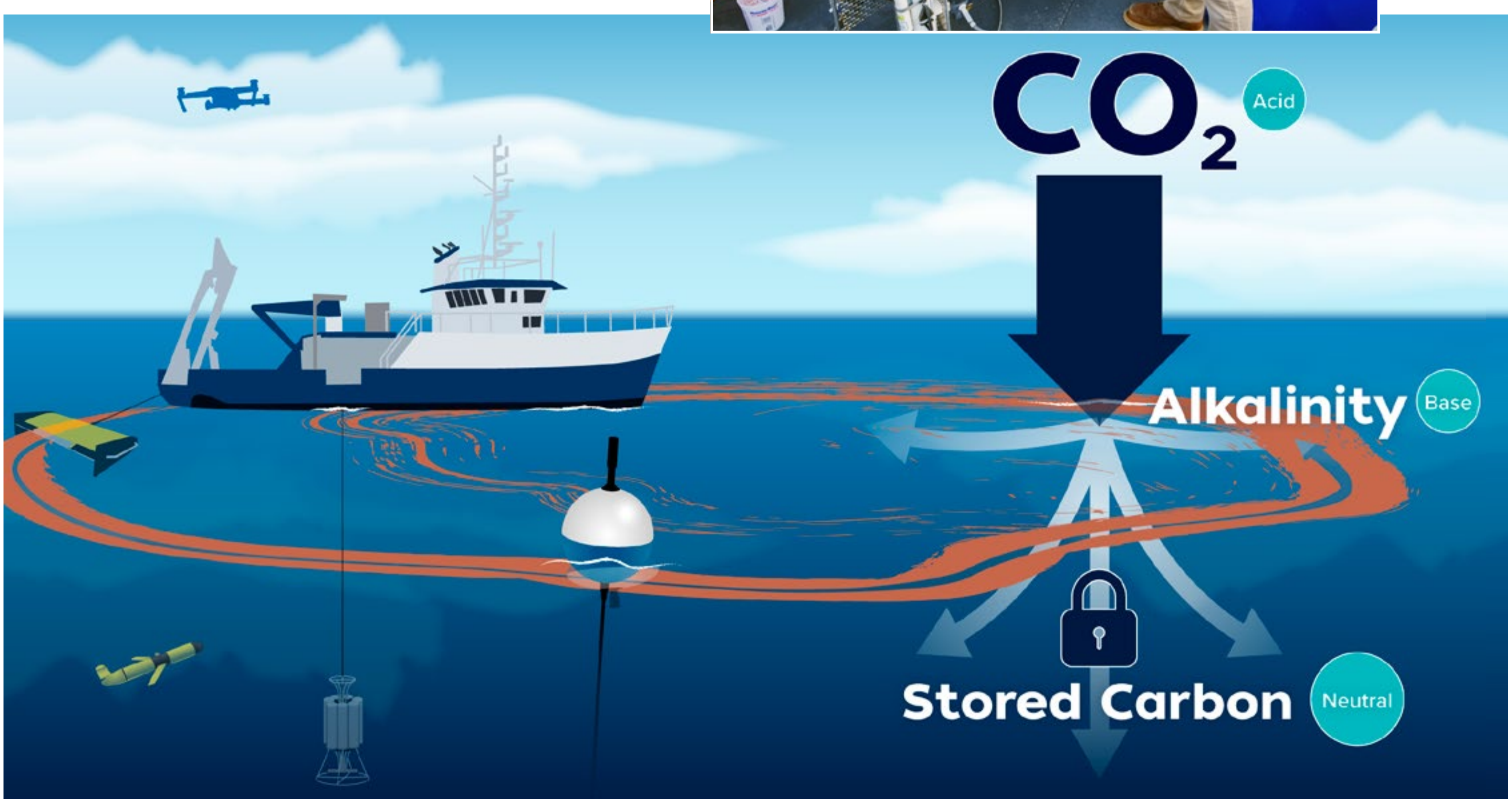
In August, Subhas carried out the first field experiment for the LOC-NESS Research Program, short for "Locking away Ocean Carbon in the Northeast Shelf and Slope." The groundbreaking analysis is funded* by the Carbon to Sea Initiative, a new program aimed at accelerating the understanding of OAE, and ICONIQ Impact, investment firm ICONIQ Capital's platform for collaborative philanthropy.

Through 2025, LOC-NESS will conduct a series of tests off the Northeast coast of the U.S. to determine OAE's atmospheric and environmental impacts—both positive and negative. Early tests will involve the release of nontoxic, fluorescent rhodamine dye and an alkaline solution into the ocean to track the dispersion of alkalinity. This work will culminate in a large-scale release of alkalinity scheduled for 2025.

While alkalinity may be a promising way to augment the ocean's uptake of carbon, Subhas maintains that the potential impact of OAE is not a "get-out-of-jail free card."

"When combined with emissions reductions," Subhas adds, "marine carbon dioxide removal approaches like OAE may help us avoid the worst effects of climate change and draw down emissions that are already in the atmosphere." ■

**Seed funding for OAE was provided in part by unrestricted gifts*



# Will Climate Change Alter the Ocean's Role in Climate?

**Marine phytoplankton, with their ability to photosynthesize, are the unsung superheroes of the ocean's biological carbon pump, which transfers about 10 gigatons of carbon from the atmosphere to the deep ocean each year.** But what happens when climate change alters the delicate balance of these primary producers as is predicted? WHOI assistant scientist Harriet Alexander is unraveling fundamental uncertainties that remain about the basic ecology and biology of phytoplankton. Her research combines classic oceanographic approaches with computational biology and molecular biology to improve the world's knowledge of the physiology, biogeochemical functions, and eco-evolutionary strategies of phytoplankton and other marine eukaryotic microbes, in coastal and open ocean systems.

"I'm working to answer three important questions," says Alexander. "First: What enables the maintenance of diverse phytoplankton communities? Second: How does genetic and functional diversity influence ecosystem function and biogeochemical cycling? And third: What defines the balance of phenotypic plasticity and intraspecific diversity in the response of phytoplankton to environmental change?"

Alexander and colleagues are incorporating the latest biological observation technologies into GO-SHIP. The GO-SHIP program unites scientists with interests in physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems, and other users and collectors of hydrographic data in a globally coordinated network of sustained hydrographic sections as part of the global ocean/climate observing system. Alexander is coordinating metagenomic (genes expressed by different organisms) and metatranscriptomic (genes expressed by the community as a whole) measurements that enable scientific census-taking among the microbial life that lives in the surface ocean. So far, her research has used the metagenomic data to recover nearly complete genomes from an important group of phytoplankton.

"Though nominally the same species group—these organisms have different genetic capabilities that may underly their ability to succeed and compete across a variety of environmental conditions," says Alexander. Changes in their gene content enable some strains to access organic nutrient sources that enhance their ability to grow and succeed in environments that other strains cannot survive in. The research highlights the importance of intraspecific (within a single species) diversity in an ecological context. "We are working to develop a basic understanding of how intraspecific differences impact food webs and carbon dynamics in a changing ocean system that we all depend on," she says. ■

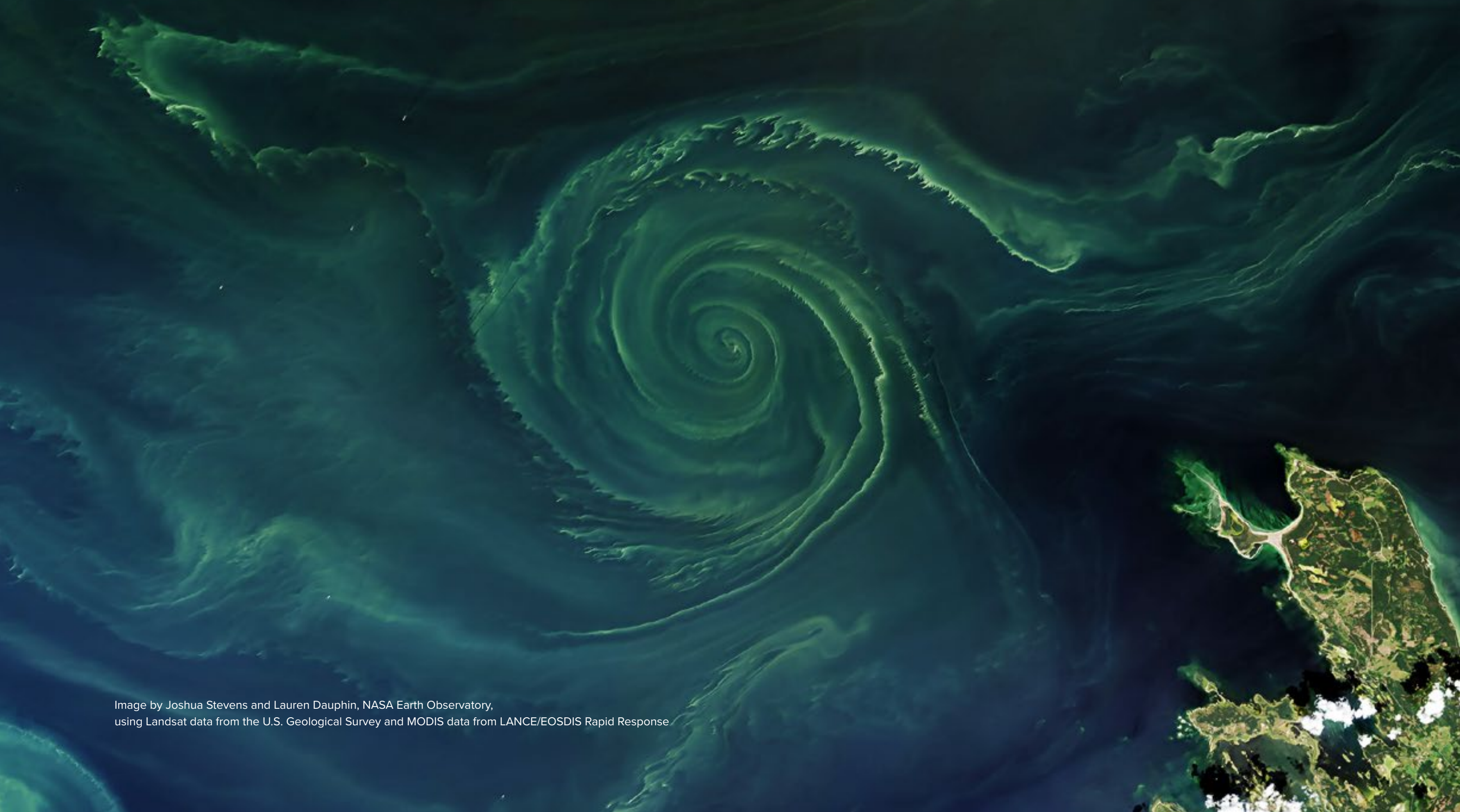


Image by Joshua Stevens and Lauren Dauphin, NASA Earth Observatory,
using Landsat data from the U.S. Geological Survey and MODIS data from LANCE/EOSDIS Rapid Response

# Diversifying Ocean Sciences

**Racial and ethnic diversity in the ocean sciences is lower than in many other STEM fields.** To help address this deficit, WHOI and other organizations are pursuing strategies for change. WHOI biologist Camrin Braun and Jaida Elcock, a PhD candidate in Braun's lab, are among those actively working to make a difference. They recently helped lead Diversifying Ocean Sciences, a year-long remote program with partners at Minorities in Shark Science, The Field School, University of Miami, University of California, Merced, and the Atlantic White Shark Conservancy.

Thirty minority graduate- and undergraduate-level students (identifying as women and non-binary) interested in STEM were selected for the program. They learned fundamental ocean science, professional development, and science communications, then participated in a grand finale, in-person "concentration" in one of three locations and topics. Braun led the week-long immersion in Marine Technology on Cape Cod along with the Atlantic White Shark Conservancy's Education Director Marianne Walsh.

"There were lots of hands-on activities, including observing white shark tagging research, drone operations for beach safety, and plenty of robotics in WHOI's David Center for Ocean Innovation," says Braun. To close out the course, the hands-on program participants gave short presentations, summarizing the personal and professional experiences the program provided them. "The presentations were extremely moving and impactful," says Braun.

Post-program evaluations echoed the positivity of the student presentations, with 100 percent of the participants calling the overall experience valuable, citing networking as the top benefit. Participants also reported that they felt like they were truly part of the community. One respondent said, "… the people I met, both peers and mentors, are the most valuable aspect of the program." Other participants said the program helped them visualize themselves in similar settings in the future and reaffirmed that they could make it in an ocean science career.

"It was rewarding for Jaida and me to be part of an exciting wave of efforts to diversify the face of oceanography. Our hope is that Diversifying Ocean Science will propel some of the recent students to pursue ocean science careers and at least feel like they have a place, a network, and an entry point to STEM fields," says Braun. ■


Photos courtesy of Minorities in Shark Science

# WHOI Sea Grant Celebrates 50 Years of Success

**WHOI Sea Grant, a WHOI- and NOAA-funded program that helps build sustainable economies and environments for Massachusetts communities, just celebrated the Big 5-0.** Through research, outreach, and education, this community-facing program—one of 34 Sea Grant programs across the nation—has helped advance public understanding of water quality, coastal resilience, aquaculture, and marine debris.

Among its many achievements, WHOI Sea Grant has seeded research leading to the creation of the U.S. National Office for Harmful Algal Blooms at WHOI and helped develop the Ocean Literacy principles used in marine education programs. WHOI provides funding from its unrestricted fund to WHOI Sea Grant, which NOAA then matches two-to-one. ■

50TH Sea Grant
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# Promoting A New Brand of New England Farming

**Growing shellfish for profit is taking hold in New England coastal communities.** But education and engagement are needed to help communities welcome this new brand of farming. To help, WHOI Sea Grant has teamed with Sea Grant programs in Connecticut and Rhode Island to take a powerful "hub approach" to engaging citizens in counties known for shellfish aquaculture. The project, Harnessing Citizen Science to Advance Southern New England Shellfish Aquaculture, benefits Massachusetts, Connecticut, and Rhode Island with its goals of educating the public and addressing community perceptions, values, and concerns about shellfishing. The project is making an impact with five broad objectives. These include expanding tools, knowledge, and public engagement reach; expanding tools, knowledge, and reach for media/press relations; expanding entry level workforce training; improving decision support tools for permitting and policy; and using social science to explore and approve acceptability of the trade.

"Shellfish aquaculture boosts the New England Blue Economy, providing jobs and income for many, and providing a popular seafood for residents and visitors," says Abigail Archer, a Fisheries and Aquaculture Specialist for WHOI Sea Grant and project lead. "This is a great example of the power of Sea Grant efforts. Together, we are helping to advance the industry and promote perceptions of shellfish aquaculture as a viable type of local farming across three states where this new form of farming is gaining traction." ■

Photo courtesy of Woods Hole Sea Grant

# STUDENTS AND POSTDOCS

# Automating Exploration

**For Amy Phung, an MIT-WHOI Joint Program student, virtual reality (VR) and robotics are a natural pairing that will accelerate ocean exploration and facilitate human connection, opening doors to profound new ways of problem-solving.** Phung is focusing her graduate work on automating the use of remotely operated vehicle (ROV) manipulator arms.

"There's a lot we don't know about the ocean, and a remarkable percentage of it remains unmapped and unexplored," says Phung, while wearing a VR headset. "Robots have lots of potential for helping us automate some of that exploration, which will provide better insights into ocean processes and our impacts on them. Robots that can help identify where we need to intervene will help us make decisions about how to protect the environment."

Automation not only rapidly scales up ocean exploration, Phung says, it can also increase access to the sea. Scientists who lack the time, ability, or funding to accompany ROVs on a ship could simply put on VR headsets to interact with the vehicles from land, saving time and money while collecting seafloor samples.

Last summer, Phung tested a group of trained ROV pilots and a mixed group of students and scientists to see if they could pick up a block from a sandbox with a robot manipulator arm, using VR headsets and topside controllers. Pilots and novices both performed the task faster with the VR interface, while novices had a hard time with the normal piloting controls. Phung then made the test more challenging, reducing the camera frame rate to refresh every 10 seconds. Even the experienced pilots struggled with the lack of visual information, but with the VR assist, they were able to perform the tasks without error or wasted time.

Phung's tests show that VR could help in poor-bandwidth situations and could also be applied to control untethered vehicles, increasing their range. But an even more pressing need is to perform tasks in low-visibility areas. One common complaint from ROV pilots is that when they disturb seafloor sediment, they must wait up to several minutes for the cloud to dissipate before moving again. Phung hopes to use acoustics to supplement or even replace the visual data coming in from ROV cameras. That could reduce the power load required to explore the dark depths, while enabling robots to differentiate between rocks and sand—even in pitch-black conditions.

One day soon, Phung envisions a fleet of "autonomous intervention vehicles" touring the world ocean on a mission to answer science questions—and perhaps pick up on trends that humans would miss entirely.

"I think in the next ten years, people won't have to specify the low-level objectives, like, 'Okay, take a sample here, take a sample there.' I think we're going to move closer to research questions—types of queries like, 'Okay, I don't care what rock you sample, I just want to know, is this type of bacteria present in this environment, yes or no?'" says Phung. "They could make their own decisions about what's interesting to sample, or maybe they just do the measurement right there."

These capabilities, says Phung, could help scientists target their research and pick up the pace of science, not only on Earth, but on other planets. ■

# ChemYak: A Kayak with Purpose

**Victoria Preston recently watched as the ChemYak, a robotic kayak rigged with sensors, navigated the shallow, ice-filled waters of Cambridge Bay in Nunavut, Canada.** Preston, a doctoral student at the time, was working with researchers probing the release of greenhouse gases in the Arctic during the annual spring thaw. The ChemYak allowed the team to take thousands of *in situ* measurements, instead of needing to bring water samples back to the lab. This clever robot, designed by engineers at WHOI for sampling in shallow water and in difficult environments, measures gases such as methane, carbon dioxide, and oxygen. It also has a sensor suite to measure conductivity, temperature, and depth.

"When we think about the power of putting instruments on robotic machines that can place those instruments optimally, it's so different than the oceanography of just a few decades ago," says Preston, who is now a WHOI postdoctoral investigator. "Having access to so much data is changing the game in many fields."

Robotic platforms like ChemYak provide valuable access to hard-to-reach places and are great for investigating specific events or areas. But their deployments are measured in hours, not weeks or months, and researchers have to make sure they're in the right place at the right time. To make accurate predictions for the ocean and our planet as the climate continues to change, scientists must combine these local observations with consistent, long-term datasets to reveal both ongoing changes and sporadic or seasonal events. ■

"HAVING ACCESS TO SO MUCH DATA IS CHANGING THE GAME IN MANY FIELDS."

—WHOI POSTDOCTORAL STUDENT VICTORIA PRESTON

# Listen Up: Study Probes Effects of Noise on Turtles

**New research shows turtles can experience temporary hearing loss from an excess of underwater noise.** This phenomenon, previously noted in other marine animals such as dolphins and fish, was not widely understood for reptiles and underscores another potential risk for aquatic turtles. This high volume of sound, referred to as underwater noise pollution, can be caused by passing ships and offshore construction.

"Our study is the first to support that these animals are vulnerable to underwater hearing loss after exposure to intense noise," said Andria Salas, WHOI postdoctoral investigator and study co-author. "We have assumed that turtles experience hearing loss when exposed to sufficiently intense sounds as observed in other animals, but there hasn't been any data collected specifically on turtles."

Aquatic turtles are predicted to rely on their sense of underwater hearing for environmental awareness, such as navigation or detection of possible predators, and some species have been shown to use underwater acoustic communication.

Using non-invasive sensors near the ears of two turtle species, investigators monitored voltages given off as a neurological response to various noises.

Salas and her collaborators, including WHOI associate scientist Aran Mooney, were surprised by how the turtles' hearing was impacted by a relatively low level of noise. The noise exposure induces what is called a temporary threshold shift (TTS), which is the resulting decrease in the animal's hearing sensitivity due to the noise. The absence of TTS studies in turtle species has led to a data gap for endangered sea turtles, and aquatic turtles more generally.

"If this occurs in nature, turtles would be less able to detect sounds in their environment on these timescales, including sounds used for communication or warning them of approaching predators," Salas said. "Over half of turtle and tortoise species are threatened, and noise pollution is an additional stressor to consider as we work towards protecting these animals."

"OUR STUDY IS THE FIRST TO SUPPORT THAT THESE ANIMALS ARE VULNERABLE TO UNDERWATER HEARING LOSS AFTER EXPOSURE TO INTENSE NOISE."

—*WHOI POSTDOCTORAL INVESTIGATOR ANDRIA SALAS*

# MIT-WHOI Joint Program Students Attend COP27

**In November 2022, two teams from the MIT-WHOI Joint Program “Climate Change Science: Oceans, Cryosphere, and Climate” had the rare opportunity to participate in the Sharm el-Sheikh Climate Change Conference (COP27) in Egypt.** They were part of 30-person delegation of WHOI administrators, scientists, and graduate students who participated in the global discussion on climate.

WHOI’s presence was ten-times larger than it was during last year’s Climate Change Conference. Each group comprised of one faculty member and five graduate students. Both groups spent a week at the conference, with two days of overlap between them. The first group was led by Sarah Das, associate scientist in Marine Geology and Geophysics, and the second by Christopher Piecuch, associate scientist in the Physical Oceanography (PO) Department.

The students and others joined hundreds of non-governmental organizations observing the conference. In conjunction with Scripps Institution of Oceanography, University of California, San Diego (UCSD), and 18 other science- and research-focused partner institutions, WHOI organized The Ocean Pavilion. Eleven of the 61 sessions held at the Ocean Pavilion over the course of the Conference were led by WHOI.

The Ocean Pavilion stood alongside other booths representing areas of climate interest. These included the Cryosphere Pavilion and the Resilience Hub. There were also booths representing various countries. This diverse set of groups was likened to an international “trade show or convention, but bigger and fancier” by PO joint program student, Glenn Liu.

COP27 resulted in a large collection of decisions addressing countries harmed by changing weather and climate as a result of human-caused emissions. The United Nations Framework Convention on Climate Change stated that in addition to reaffirming previous UN climate agreements, these decisions worked to “establish new funding arrangements, as well as a dedicated fund, to assist developing countries in responding to loss and damage.”

Plans are underway for WHOI to return to COP28, to be held in Dubai, United Arab Emirates, starting on November 30, 2023. ■


# Imaging Bot Detects Harmful Algal Blooms in the Arctic

**Not long ago, enroute to the Bering Strait, MIT-WHOI PhD student Evie Fachon hoped to learn more about a toxic species of phytoplankton known as** ***Alexandrium catenella*****.** With the Alaskan Arctic warming faster than almost anywhere else in the world, she and other members of WHOI's Anderson Research Lab were concerned about the possible northward spread of this dangerous species. Since 2018, they have made multiple trips to sample the icy waters of the Bering Strait and the Chukchi sea to its north. Instead of a routine cruise, the team's research became the center of the first real-time detection of an unprecedented toxic bloom in Alaskan Arctic waters, necessitating multiple risk advisories to remote communities.

Aboard the R/V *Norseman II*, Fachon carried a draft of a health advisory intended to warn residents in the sparse communities of the Alaskan Arctic to not eat shellfish or other potentially toxic marine animals. She, and her advisor, WHOI Senior Biologist Don Anderson, and the cruise's Chief Scientist Bob Pickart, agreed with local health officials and Alaska Sea Grant to distribute it if the science team found concentrations of a toxic algae species above 1,000 cells per liter—a threshold known to be dangerous. Just five days into the 28-day cruise, the team's automated microscope, a WHOI-designed tool called Imaging Flow Cytobot (IFCB), detected well over 18,000 cells per liter outside of Gambell, Alaska. A few days later, 30,000. Weeks later, 100,000. Fachon and others had been to Alaska in the past and hadn't seen anything concerning.

"So, I was really not expecting to warn communities so soon after we left the dock," she said.

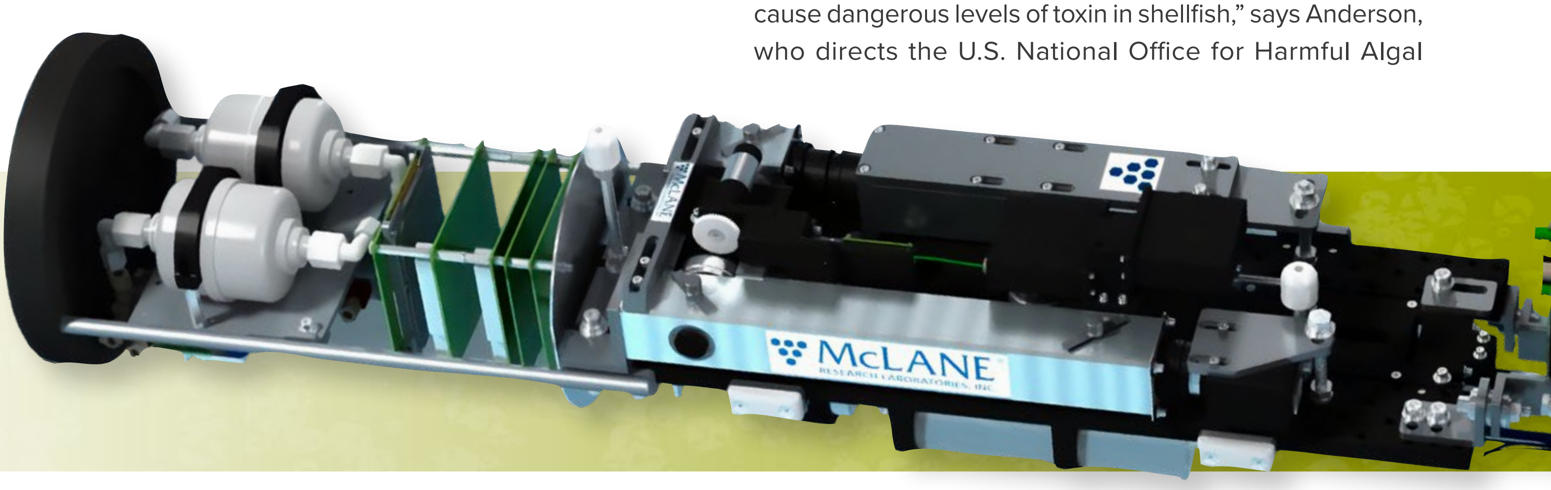
The culprit, *Alexandrium*, is a common catalyst behind harmful algal blooms (HABs) worldwide. In areas like the Gulf of Maine, its toxins—which cause paralysis and death in humans and aquatic animals—have tainted annual shellfish harvests for decades, leading to recalls and closures. In the rugged Alaskan Arctic, where subsistence harvesting of marine life is the primary food source for many, the contamination risks are significant and broad. There, in the absence of routine monitoring programs, food safety checks are hard to come by.

Twenty-four hours after the research team notified shoreside health officials, several email advisories were sent out to residents in six major communities across the Bering Strait and Seward Peninsula. Meanwhile, the *Norseman II* team continued tracking the bloom north.

"If this advisory wasn't issued, food with high concentrations of the algae could have been consumed," says Emma Pate, an environmental coordinator with Norton Sound Health Corporation who helped disseminate the advisory.

For now, the region seems to have dodged a major bullet. To date, there have been no reported illnesses or deaths. Still, the unprecedented scale of this bloom has researchers worried.

"In the Gulf of Maine, where we've studied *Alexandrium* and resulting shellfish closures, it's typical to see a few thousand cells per liter, and that is more than enough to cause dangerous levels of toxin in shellfish," says Anderson, who directs the U.S. National Office for Harmful Algal



Blooms. "But it's a rare event when we see 20- to 30,000 or more, so this was a shock."

Historically, the frigid subarctic waters of the Bering Strait and Chukchi Sea northwest of Alaska have been a buffer against frequent HABs. That's changed with planetary warming.

Warming from climate change has increased average bottom water temperatures, more than doubling the rate at which these cysts now hatch and advancing the start of the seasonal bloom by three weeks. In total, this Alaskan Arctic "cyst bed," is more than 15-times larger than that in the Gulf of Maine and is one of the densest in the world. This "sleeping giant" is a point of concern for Anderson and his lab mates, who fear that if it awakes it could be the source of recurrent, massive blooms as waters warm and create a cycle of locally-originating harmful algal blooms in the Chukchi Sea and north Bering Strait—something for which Alaskan Arctic monitoring efforts aren't yet prepared.

Fortunately, portable technologies like the Imaging Flow Cytobot continue to streamline HAB detection and analysis. Before the device was invented in 2018, hundreds of water samples from the region had to be flown across the country to WHOI, where algal cells were meticulously counted and analyzed under a microscope—a process that often took months. By then, an advisory to coastal communities would have been useless.

Today, the Cytobot helps scientists monitor *Alexandrium* cells round-the-clock, without anyone ever stepping off the boat. With it, WHOI's HAB scientists were able to provide Alaskan Arctic residents with the first real-time risk advisories, something Anderson and Fachon herald as a major advancement. ■

"I WAS REALLY NOT EXPECTING TO WARN COMMUNITIES SO SOON AFTER WE LEFT THE DOCK."

*—MIT-WHOI PHD STUDENT EVIE FACHON*

# How Marine Predators Find Food Hotspots in Open Ocean Deserts

**A study published in the journal *Nature* and led by scientists at WHOI and University of Washington Applied Physics Laboratory (UW APL) has found that marine predators, such as tunas, billfishes, and sharks aggregate in anticyclonic, or clockwise-rotating, ocean eddies (mobile, coherent bodies of water).** As these anticyclonic eddies move throughout the open ocean, the study suggests that the predators are also moving with them, foraging on the high deep-ocean biomass contained within.

"We discovered that anticyclonic eddies—rotating clockwise in the Northern Hemisphere—were associated with increased pelagic predator catch compared with eddies rotating counter-clockwise and regions outside eddies," said Martin Arostegui, a WHOI postdoctoral scholar and lead author of the paper. "Increased predator abundance in these eddies is probably driven by predator selection for habitats hosting better feeding opportunities."

The study included collaborators from the National Oceanic and Atmospheric Administration's (NOAA) Pacific Islands Fisheries Science Center. It focused on more than 20 years of commercial fishery and satellite data collected from the North Pacific Subtropical Gyre—a vast region that is nutrient-poor but supports predator fishes that are central to the economic and food security of Pacific Islands nations and communities.

Photo courtesy of Pat Ford Photography

The research team assessed an ecologically diverse community of predators varying in latitudes, ocean depths, and physiology (cold vs. warm-blooded).

Although there is a growing body of research showing that diverse predators associate with eddies, this is the first study to focus on the subtropical gyre, which is the largest ecosystem on Earth. The research team was able to investigate predator catch patterns with respect to the eddies, concluding that eddies influence open ocean ecosystems from the bottom to the top of the food chain. This discovery suggests a fundamental relationship between predator foraging opportunities and the underlying physics of the ocean.

"The idea that these eddies contain more food means they're serving as mobile hotspots in the ocean desert that predators encounter, target, and stay in to feed," said Arostegui.

The findings highlight the connection between the surface and deep ocean, which must be considered in impact assessments of future deep-sea industries. As deep-sea prey fisheries continue to expand, there comes the need for more information on deep-sea ecology, particularly how much deep-prey biomass can be harvested by fisheries without negatively affecting dependent predators or the ocean's ability to store carbon and regulate the climate. A better understanding of the ecosystem services provided by the deep ocean via eddies, particularly with respect to predator fisheries, will help inform responsible use of deep-ocean resources.

"The ocean benefits predators, which then benefit humans as a food source," Arostegui said. "Harvesting the food that our food eats is something we need to understand in order to ensure the methods are sustainable for both the prey and the predators that rely on them. That is critical to ensuring both ocean health and human well-being as we continue to rely on these animals for food." ■

# NEW HIRES

Photo courtesy of Gregory Britten

## GREGORY BRITTEN BIOLOGY

Gregory Britten is a biological oceanographer who explores complementary research themes related to marine primary productivity, food webs, plankton ecology, ecosystem science, and fisheries sustainability. Focal areas include regional and global modeling of marine phytoplankton production, the impact of environmental variability on marine ecosystems and food webs, and the productivity of exploited fish populations. Britten does basic and applied modeling to understand how systems work, while contributing to science-based decision making, particularly in the context of climate and oceanographic change. At WHOI, Britten is working with colleagues and MIT scientists to examine the ecosystem dynamics of the Northwest Atlantic. Projects include efforts to understand plankton ecology and support. He holds B.Sc. and M.Sc. degrees from Dalhousie University in Halifax, Canada; M.Sc. and Ph.D. degrees from the University of California, Irvine; and completed his postdoctoral studies at the Massachusetts Institute of Technology. Britten joined WHOI in November 2022, as an Assistant Scientist in the Biology Department.

Photo courtesy of Julia Guimond

## JULIA GUIMOND APPLIED OCEAN PHYSICS AND ENGINEERING

Julia Guimond is a groundwater hydrologist studying interactions between coastal aquifers and the ocean. Groundwater is a vital resource for both coastal ecosystems and communities, but coastal groundwater is increasingly vulnerable to climate change impacts affecting both terrestrial and marine environments. A WHOI Assistant Scientist, her research centers around the question: How will climate change alter coastal groundwater systems and dependent ecosystems? She is particularly interested in better understanding coastal Arctic environments, where permafrost thaw and sea ice loss are rapidly altering land-sea interactions. In a broader context, through interdisciplinary collaborations, Guimond seeks to address how changing groundwater dynamics will alter the movement and storage of carbon in the coastal zone. She graduated from Brown University in 2013 with an Honors ScB in Geology-Biology. After working for the New Hampshire Department of Environmental Services' Watershed Program, she attended the University of Delaware where she obtained her Ph.D. in Geological Sciences in 2020. Guimond was a National Science Foundation Postdoctoral Fellow before joining WHOI in January 2023.

## LAURA MOTTA

CHEMISTRY AND GEOCHEMISTRY

Laura Motta's research involves an interdisciplinary approach to answering critical questions about marine biogeochemical cycles via seagoing fieldwork, laboratory experiments, and theoretical chemistry. The central theme of her research is the measurement, modeling, and interpretation of stable isotope patterns (or fingerprints) found in marine environments. She is particularly interested in non-traditional isotope effects and is mainly studying the marine biogeochemical cycle of mercury, a neurotoxic pollutant of public health concern projected to increase with climate change. Motta graduated with a B.A. in Chemistry from Rutgers University and holds a dual Ph.D. in Environmental Sciences and Theoretical Chemistry from the University of Michigan. She was a postdoc at the University at Buffalo, working in theoretical chemistry of heavy elements, and spent time in South Korea as a postdoc at POSTECH, working on marine plankton, then joined WHOI in February of 2023 as an Assistant Scientist in the Marine Chemistry and Geochemistry department.

Photo courtesy of Laura Motta

## ELIZABETH SIBERT

GEOLOGY AND GEOPHYSICS

Elizabeth Sibert is an oceanographer whose research investigates how marine ecosystems, particularly consumers such as fish and sharks, respond to global change. Working at the intersection of biology and geology, Sibert uses microfossil fish teeth and shark scales ('ichthyoliths') preserved in deep-sea sediment cores to investigate marine consumer dynamics through earth's history, and across major global climate change and mass extinction events, to better understand the interactions between marine ecosystems and environmental change. She graduated with a BS in Biology from the University of California, San Diego in 2011 and completed her graduate studies at Scripps Institution of Oceanography in 2016. Following her Ph.D., Sibert spent four years as a Junior Fellow in the Harvard Society of Fellows (2016-2020), before moving to Yale, first as an inaugural Hutchinson Fellow at the Yale Institute for Biospheric Studies (2020-2022) and then as an Associate Research Scientist (2022-2023). She joined WHOI as an Assistant Scientist in Geology and Geophysics in April 2023.

Photo courtesy of Maddie Smith

## MADISON "MADDIE" SMITH APPLIED OCEAN PHYSICS AND ENGINEERING

Maddie Smith specializes in sea ice; waves and wave-ice interactions; upper ocean processes; Arctic and Antarctic fieldwork; and integrating observations and climate models. Motivated by the loss of sea ice in a rapidly changing climate, her research uses observations and modeling approaches to understand how sea ice interacts with the ocean. Her fieldwork has taken her to the oceans at both ends of the Earth, including participation in the summer leg of the year-long MOSAiC expedition in the Arctic. Smith completed her Ph.D. in Civil & Environmental Engineering at the University of Washington, exploring the role of surface waves and turbulence in the autumn Arctic Ocean. She received her B.A. in Earth & Oceanographic Studies and Environmental Science from Bowdoin College in Brunswick, Maine, where she first dreamed of exploring the Arctic while learning about the transpolar drift of Fridtjof Nansen. Smith joined WHOI in September 2022 as an Assistant Scientist in the Applied Ocean Physics and Engineering Department.

## SHAWNA HUNT, DIRECTOR OF LEARNING AND DEVELOPMENT

PEOPLE OPERATIONS

Shawna Hunt specializes in Organizational Development, Leadership Development, Performance Management, and Employee Engagement. With a career in Learning and Development that began in 2001, she has worked in a wide variety of learning roles, and most recently served as a Senior Consultant with the Gallup Organization. Her experience serves as a strong foundation for her current role at WHOI, where she aims to advance professional learning and development initiatives. Hunt believes that one of the keys to groundbreaking research and innovation, especially in a field as dynamic as ocean science, is a commitment to on-going growth and development. She joined WHOI in June of this year as the Director of Learning and Development.

Photo courtesy of Shawna Hunt

# RESEARCH ACCELERATOR

# The Power of the Research Accelerator Fund

## LETTER FROM THE DEPUTY DIRECTOR AND VICE PRESIDENT FOR SCIENCE AND ENGINEERING

**Over the past year, WHOI research and engineering continued to focus on innovation and global problem solving.** Enabled by advanced technologies, such as artificial intelligence, automation, and supercomputing, WHOI scientists and engineers devised novel ways of helping endangered marine life, informed better resource management, and unraveled the ocean processes that people everywhere depend on. Your support of the WHOI Research Accelerator Fund is what makes this impactful work possible.

This report highlights a few of the many projects your generosity has advanced. In the following pages you can read about a game-changing tool that senses greenhouse gasses in the ocean, a project to track endangered emperor penguins and aid in their protections, and research that is exploring the micromachinery of Earth's life-support system and probing the molecular underpinnings of long-term carbon sequestration.

Since the Research Accelerator model was established in 2019, your strategic support for high-risk, high-reward research has empowered numerous scientists across all six WHOI departments, enabling scientists in each of WHOI's disciplines to rapidly respond to emerging opportunities.

In all, your generosity has provided nearly $11 million in endowment and almost $4 million in current-use funds, translating into support for more than 26 projects this year. From July 2022 through August 2023 alone, Research Accelerator donors have committed $3.6 million, enabling WHOI to leverage a remarkable $16.6 million-plus from external agencies, many for multi-year projects.

We are grateful to all who have supported the WHOI Research Accelerator Fund and look forward to continuing to accelerate our search for new knowledge and solutions in the coming year.

Sincerely,

Richard W. Murray

Richard "Rick" W. Murray
Deputy Director and Vice President for Science and Engineering

# Building a Global Library of Underwater Biological Sounds

**Growing threats of climate change, habitat degradation, and dramatic biodiversity loss resulting from human activity mean there is an urgent need to document, quantify, and understand the underwater biological realm.** To help fill this need, scientists are building a Global Library of Underwater Biological Sounds (GLUBS).

The library will be comprised of underwater soundscapes provided by passive acoustic monitoring, or PAM. “Acoustic soundscapes provide a non-invasive window into a world that is notoriously challenging to study,” say Aran Mooney and Laela Sayigh, two WHOI scientists who are collaborating on GLUBS with scientists from around the world. The library will provide soundscapes and a catalog of diverse animal sounds that can offer audible insights into the presence of various species as well as the condition of habitats, critical behaviors, and biodiversity hotspots.

For GLUBS to move forward, the global PAM community needed to gather and chart a course for increased data sharing and accessibility. So, Mooney and Sayigh planned and hosted an April 2023 workshop to co-design a conceptual blueprint platform for GLUBS.

“We convened 30 experts who joined in a common goal we all care about: marine conservation,” says Sayigh.

Together, the group planned a multi-level reference e-library for underwater biological sounds. The new audio library will incorporate existing libraries from around the world, repositories of annotated sound sources, a training platform for acoustic AI algorithms, and a citizen science-based application for public users.

“The ocean is a noisy place and the power of sound in ocean science cannot be overstated,” says Mooney. “The Global Library of Underwater Biological Sounds will be a welcome resource for tracking unprecedented changes to the ocean environment.”

# Exploring the Micro Machinery of Earth's Life Support System

**Marine microbial populations are the engines of Earth's life support system, exerting influence on key biogeochemical cycles.** For example, ocean microbes, including algae and bacteria, are directly mediating the carbon and nitrogen cycles.

"Within each microbe, thousands of proteins are produced—each with specific functional and catalytic roles," says WHOI scientist Makoto Saito, who is innovating ways to explore this molecular machinery. He and his colleagues are using a high-throughput native protein measurement approach called proteomics to examine microbial enzymes. "We couple the measurements with enzymatic assays to map the many functional capabilities within each organism, effectively disentangling the capabilities of these microscopic machines," says Saito.

The investigators are applying these and other proteomics techniques to study naturally occurring ocean microbial populations and observe how they behave under both normal and changing conditions. The research has the potential to help elucidate how Earth's biogeochemical life support system is controlled by microbial biochemistry and how it can inform Earth-predictive modeling efforts. ■

# Zooming in on Marine Plankton that Power the Planet

**Marine plankton help power global productivity and biogeochemical cycling.** “Their functions are strongly regulated by community composition and interactions among organisms that span a huge range of phylogenetic, morphological, physiological, and trophic diversity,” says Heidi Sosik, a WHOI Senior Scientist. “Yet knowledge of these organisms and interactions among them continue to be limited by observational challenges associated with elevated levels of spatial and temporal variability in a demanding ocean environment.”

The good news is there are recent and exciting advances in microscopic imaging approaches. This is especially true of automated systems that can be deployed from a variety of oceanographic sensing platforms. But marine scientists still need to fill an important gap in taxonomic and morphological resolution in the range of large microplankton and small mesoplankton. “This size range includes very large chain-forming diatoms, filamentous cyanobacteria, large protozoans (Radiolaria), and small crustaceans, all of which are important players in marine ecosystems,” says Sosik. “These organisms are known to be highly patchy in space and time so there is a strong need for targeted approaches to observe them.”

To fill the gap, Sosik is prototyping a new “micro” deep-focus imaging instrument with a pixel resolution and sample volume that can characterize required morphological detail and spatio-temporal variability. “The tool leverages lessons learned from existing imaging-in-flow cytometry (cell property measurement) and *in situ* shadowgraph imaging,” says Sosik.

She and her collaborators are using an iterative approach to design, evaluate, and field test the new instrument. Field tests are happening on funded research cruises as part of the Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) project.

In anticipation of the new instrument’s success, Sosik has forged a partnership with Bellamare LLC, a small company that can make prototypes accessible to the broader research community as soon as they pass field testing.

“Better tools for observing marine plankton are essential for understanding so many aspects of how ocean ecosystems function,” she says ■

Image courtesy of David Liittschwager

# Tagging Along to Help Threatened Emperor Penguins

**One might consider emperor penguins to be Antarctica's rather large canaries in the coal mine.** "They are a sentinel species; they highlight the vulnerability of ice-dependent organisms in a rapidly warming world," says Dan Zitterbart, a WHOI scientist who is developing and using tagging technologies to remotely sense these birds and their ecosystem's health. The research is critical. Just last year, emperor penguins were listed as a threatened species under the Endangered Species Act due to their shrinking sea ice habitat.

In 2017, Zitterbart, head of WHOI's Marine Animal Remote Sensing Lab, and his team started a long-term monitoring of the oceanographic features of the Weddell Sea and eastern Antarctica by equipping 60 RFID-tagged emperor penguins with Very High Frequency (VHF) radio, Global Positioning System (GPS), Temperature-Depth-Accelerometry recorders (TDR-Acc).

Recently, the team used similar technology as part of a long-term, large-scale research project called MARE (Monitoring the health of the Antarctic maRine Ecosystems) using the emperor penguin as a sentinel. Specifically, during a field expedition from November 2022 – January 2023, Zitterbart and others deployed ten SPOT 283 tags, which provided a 2D location of the tagged birds through the ARGOS satellite system and four SPLASH 367 tags which, in addition to 2D location, also provided dive histograms. The tags provided a "bird's eye view" of juvenile emperor penguins that could inform species conservation programs.

Specifically, the study revealed that the juveniles swim much farther north than assumed, and therefore far beyond the boundaries of the Marine Protected Area (MPA). "That means the MPA designating governing bodies need to account for juvenile populations when estimating a species range," says Zitterbart. "Usually, only the adult population is considered, but because emperor penguins have such a low fecundity and juvenile survival rate of just 10 percent, protecting juveniles is as important as protecting adults."

According to Zitterbart, recent sea ice loss is having a massive impact on emperor penguins. In 2023, four colonies on the west Antarctic Peninsula had a total breeding failure because the sea ice broke up too early. "The time to study this species and protect its future habitat from additional pressures is now," he warns. ■

Photo courtesy of Dan Zitterbart

# A Molecular View of Ocean Carbon Sequestration

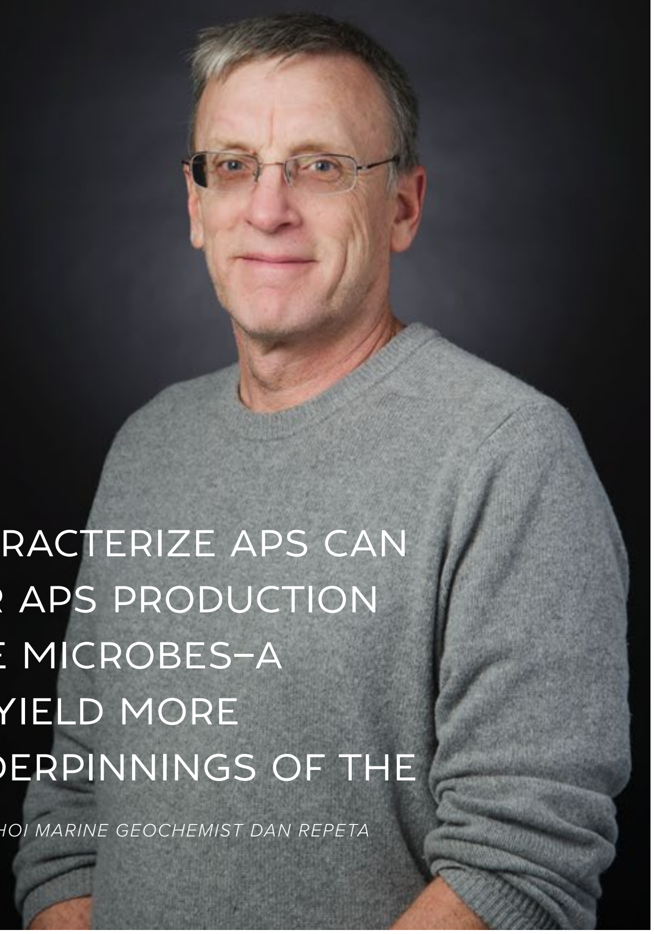
**Important questions remain about the chemistry that drives the biological carbon pump that sequesters carbon dioxide from the atmosphere into the ocean.** In this process, phytoplankton fix carbon dioxide into organic matter that then sinks into the deep ocean as particles or as dissolved organic matter (DOM). Most of this carbon is remineralized to carbon dioxide, which builds up until it eventually leaves the ocean—but some of the carbon doesn't mineralize and is stored deep in the ocean for many thousands of years as recalcitrant DOM.

A question WHOI marine geochemist Dan Repeta seeks to answer is: "Why is some carbon remineralized while other carbon is recalcitrant for thousands of years? Repeta is exploring the structure of acylated polysaccharide or "APS," a very specific polysaccharide that represents a large fraction of recalcitrant DOM in marine, hypersaline, and freshwaters.

All available evidence suggests that APS accumulation is due to novel structural features of the polysaccharide. However, despite repeated attempts, the structure of APS has not been determined since it was first reported in 1992. "APS is highly self-reactive and traditional approaches to characterization destroy most of the polymer, yielding little structural information," says Repeta.

By systematically studying the effects of traditional methods on APS, he has developed new protocols to minimize self-reaction that should allow for structural characterization to a level that will allow scientists to link polysaccharide structure to recalcitrance.

"When scaled appropriately, the approach naturally yields APS oligosaccharides, carbohydrates that can be screened for microbial metabolism, allowing scientists to identify the key degradation steps of APS," says Repeta. "The protocols used to characterize APS can also be used to screen for APS production by major groups of marine microbes—a breakthrough that could yield more information about the underpinnings of the biological carbon pump." ■



"THE PROTOCOLS USED TO CHARACTERIZE APS CAN ALSO BE USED TO SCREEN FOR APS PRODUCTION BY MAJOR GROUPS OF MARINE MICROBES–A BREAKTHROUGH THAT COULD YIELD MORE INFORMATION ABOUT THE UNDERPINNINGS OF THE BIOLOGICAL CARBON PUMP." *—WHOI MARINE GEOCHEMIST DAN REPETA*

# Introducing SAGE: A New Tool for Ocean Science

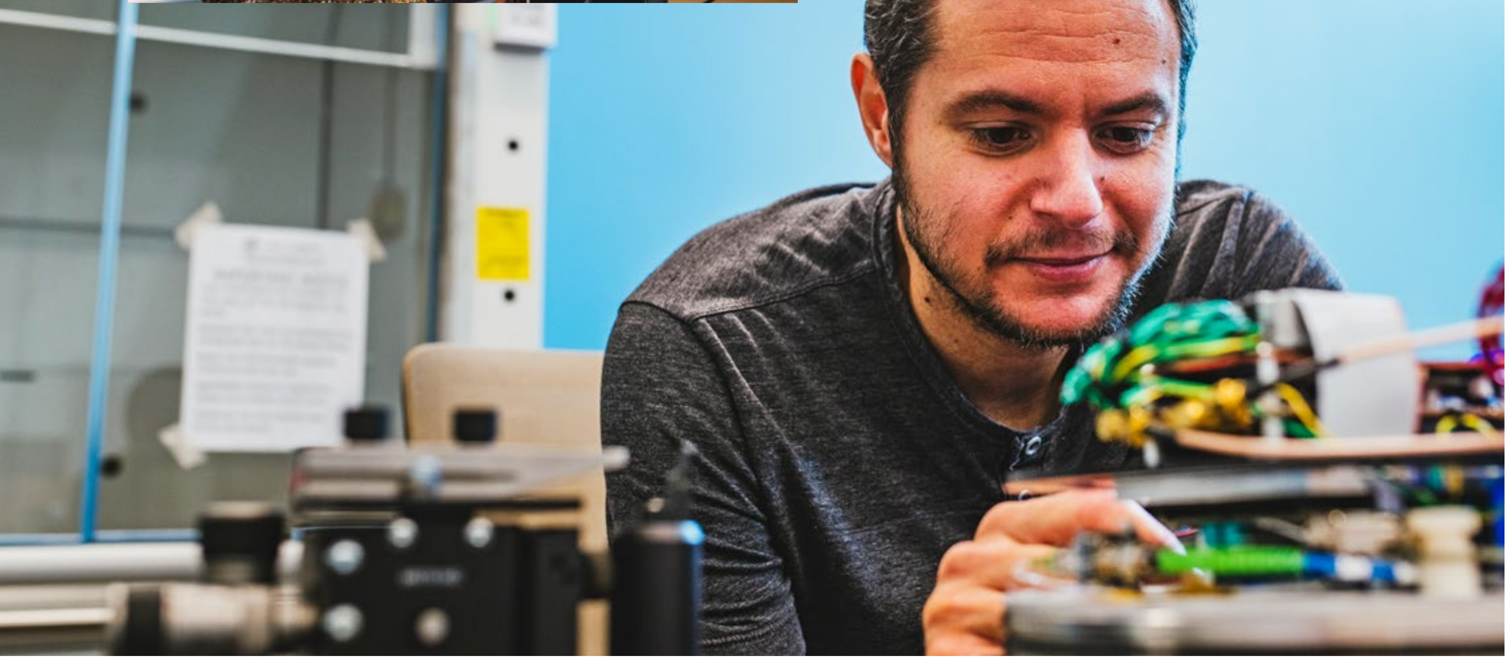
**The ability to accurately measure greenhouse gases such as methane and carbon dioxide in deep water is critical to understanding the ocean's role in climate.** WHOI engineers Anna Michel and Jason Kapit, wizards at designing cool tools for ocean scientists, are on the case. Testing of their new Sensor for Aqueous Gases for the Environment, or SAGE, has proven its ability to measure methane in the deep ocean. "To date, SAGE has been deployed and tested on several deep-diving vehicles, including ROV *Jason*, AUV *Sentry*, and ROV *Aurora*," says Michel.

While SAGE worked well in its first trials, Kapit and Michel are tweaking the instrument, and adding new capabilities, such as the capacity to work at full ocean depth. The engineers will test the improved SAGE on a 2024 cruise to the Aleutian Trench, where the maximum depth is 26,604 feet—nearly as deep as Mt. Everest is high. The engineers have also developed a bench-top SAGE that can be used for field measurements.

"It was tested in France this summer during an exploration of coastal environments, where it measured methane emissions from salt production farms," says Michel. But there is yet more work to do on SAGE. "Next steps include maturing the sensor to a state suitable for scalability, possible commercial transition, and broader oceanographic and environmental use," says Michel.

She and Kapit are now fabricating and testing additional versions of SAGE, including those that target other important gases, such as carbon dioxide, and implementing beta testing and risk reduction.

"The performance, versatility, and utility of the new sensor are very encouraging," says Michel. "We see great potential in developing additional, improved versions of SAGE for a variety of applications to benefit the entire ocean science and monitoring community." ■



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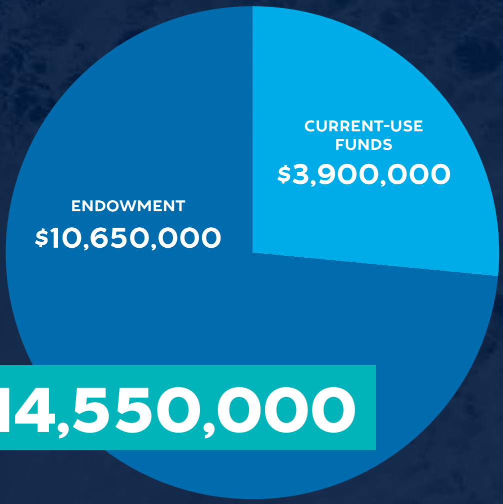


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