COOPERATIVE INSTITUTE FOR CLIMATE, OCEAN, AND ECOSYSTEM STUDIES

CICOES MAGAZINE 2025

UNIVERSITY of WASHINGTON | UAF UNIVERSITY OF ALASKA FAIRBANKS | Oregon State University

Cooperative Institute for
CLIMATE, OCEAN &
ECOSYSTEM STUDIES

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ON THE COVER
UW researcher Craig Norrie conducting night-time fieldwork
Photo: Craig Norrie
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OPPOSITE PAGE
Shannon Brown rolling the autonomous eDNA sampler onto the deck of the NOAA *Oscar Dyson* prior to deployment
Photo: Natalie Monacci
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THE HOME DEPOT

Photo: College of the Environment

From the Director

John Horne

> *"Thanks to all for your hard work to adapt to what seemed like a constantly evolving federal landscape that contained uncertain rules and short lead times."*

It has been an adventurous, stressful, and yet productive year. I am not sure anyone could have predicted the events of the last year, I certainly couldn't, but am happy to share that CICOES successfully rose to its challenges.

A year ago, we had just finished completing and submitting our CICOES renewal proposal and were wondering what impact(s) a new administration would have on our funding and operations. Responding to events that subsequently unfolded required a lot of flexibility and quick responses from the entire CICOES community. Thanks to all for your hard work to adapt to what seemed like a constantly evolving federal landscape that contained uncertain rules and short lead times.

It's important to highlight our collective accomplishments this year:

- Approval of our new Cooperative Agreement (2025–2030).
- Receiving a no-cost-extension for our previous Cooperative Agreement.
- Revising our administrative operations to conform to new or altered federal and university policies.
- National leadership of the Cooperative Institute enterprise that continued constructive interactions with NOAA headquarters.
- Navigating a dynamic federal fy25 proposal season with its new submission requirements and delayed processing.
- Successful re-hiring of former employees that had a brief stint with the federal government workforce.
- Capitol Hill advocacy on the vital contributions of CICOES and Cooperative Institutes to NOAA's mission in response to the fy26 President's budget.
- Supporting our co-located employees housed at federal laboratories through a six-week government shutdown.

I want to make sure that I thank all CICOES deputy directors and financial administrators for their help in successfully tackling challenges associated with each of these accomplishments.

Through all these events, I am happy to report that CICOES received nearly all its authorized fy25 NOAA funding under the Cooperative Agreement. We

Photos: Craig Norrie

Hood Canal, Washington

were one of the first Cooperative Institutes to have our fy25 proposal package authorized by Commerce Secretary Lutnick and, unfortunately, the last Cooperative Institute to receive the final 35% of its expected funding. There was stress and trepidation, and we need to thank the Office of Oceanic and Atmospheric Research (OAR) leadership at NOAA headquarters who guided and assisted our proposals through the federal administratium (this is not a neologism nor a misprint).

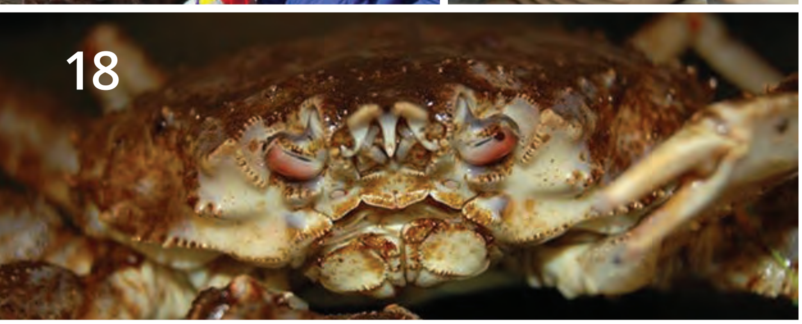
Changes in Washington State funding also impacted CICOES operations. Cuts to the University of Washington's budget led to cuts in funds transferred from the College of the Environment Dean's Office to CICOES. In response to the combined state cuts and federal policy changes, CICOES enacted changes to reduce our expenditures for the last half of 2025 and will continue to examine our operations and initiative programs to reduce costs, increase administrative efficiency, and to minimize impacts on CICOES services and programs. This may be an ongoing exercise as additional state cuts are predicted, and the uncertainty of sustained federal funding continues. Despite these new challenges, our mission hasn't changed. CICOES will continue our collaborative research, education, and outreach efforts to benefit both NOAA's mission and our worldwide community.

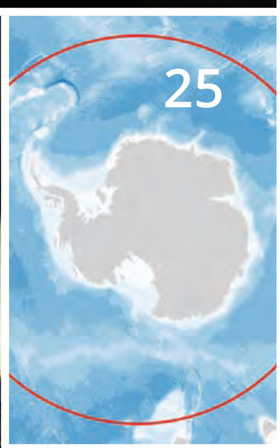
Congratulations and thanks to everyone for their dedication this year. We all need to recognize that there has been unprecedented change and acknowledge that it is probably not over yet. I do expect that there will be new opportunities over the next year or two and that we should be open and poised to take advantage of them when they arise. The value and impact of your work have not changed, just as the appreciation for your ongoing efforts has not diminished in any way.

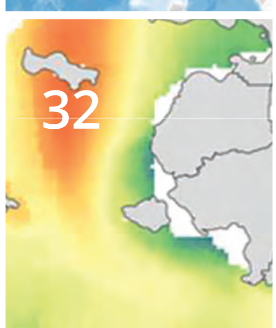
I truly wish that everyone has a productive and more predictable 2026.

“Despite these new challenges, our mission hasn't changed. CICOES will continue our collaborative research, education, and outreach efforts to benefit both NOAA's mission and our worldwide community.”

John K. Horne, *Executive Director*







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Growing Resilient Oysters

Photo: Craig Norrie

GENETICS, ENVIRONMENTAL STRESS, AND THE FUTURE OF SHELLFISH FARMING

—by Craig Norrie, UW School of Aquatic & Fishery Sciences

MONITORING OYSTERS AT NIGHT

It's two in the morning on a cold November night, and I'm hunched over oyster racks on the middle of a blustery tide flat in Hood Canal. If I wasn't wearing thick gloves to keep the barnacle-encrusted oyster cages from tearing my hands to shreds, they would be numb and stiff from the cold. Occasional snores from a nearby snoozing seal punctuate the whistle of the wind through the racks. I am surrounded by thousands of oysters, destined to be served in the finest restaurants across the country.

The reason I'm at Baywater Shellfish Farm in the middle of the night is to monitor oysters as part of a collaborative project between UW (Jackie Padilla Gamiño and me), the Washington aquaculture industry (Joth Davis from Baywater Shellfish), and NOAA (Paul McElhany and Shallin Busch), working as a team to understand how climate change will impact Washington's multimillion-dollar Pacific oyster industry.

> *"Washington state is the country's leading producer of farmed oysters."*

Chelsea Farms, one of our partners, is an intertidal farm, where the oysters are uncovered every day.

Shellfish aquaculture is seen as a sustainable way to help meet the protein needs of a human population that is predicted to hit 10 billion by 2050. Washington state is the country's leading producer of farmed oysters; the industry contributes $270 million to the state economy annually and supports over 3,200 jobs. In addition to its economic importance, shellfish farming provides valuable ecosystem services, such as filtering water and creating habitat for other marine species.

As human-driven carbon dioxide emissions drive increased marine and atmospheric temperatures, cause the oceans to become more acidic, and reduce the oxygen concentrations in coastal and offshore waters, shellfish are subject to increasingly stressful conditions. The combination of these environmental stressors can negatively impact shellfish survival, and in turn, reduce the economic and ecological benefits that they provide.

At increased temperatures, shellfish physiology can be pushed to its edge, especially as many shellfish are grown in an intertidal environment where they experience both higher water and air temperatures. For calcifiers (shell builders), increased ocean acidity driven by the absorption of carbon dioxide from the atmosphere makes it harder to build and maintain shells, and reduced oxygen levels caused by the breakdown of organic matter can make it harder for oysters to breathe. These converging stressors are already being noticed by shellfish farmers, prompting them to partner with researchers to understand when, where, and why losses occur.

But not all oysters respond to climate change in the same way. Our research is particularly focused on understanding how triploid oysters (oysters with an extra set of chromosomes) are impacted by environmental stressors.

TRIPLOID OYSTERS—EXTRA CHROMOSOMES, EXTRA UNCERTAINTY

There's an adage about oysters: don't eat them in months without the letter R—May, June, July, and August. This is partly because during the summer months, oysters are preparing to spawn, and they start to develop gonads: eggs and sperm. Gonads have a creamy texture that most consumers don't find appetizing.

But triploid oysters have three sets of chromosomes; one of the side effects of this is that they don't generally spawn, and therefore they're gonad-free. Thanks to triploid oysters, we can enjoy the quintessential summer ritual of slurping down freshly shucked oysters on a sunny patio with a chilled glass of white wine, sans creamy gonads coating the inside of our mouths. Triploidy is the same approach used to produce seedless watermelons or grapes. Because consumers appreciate triploid oysters (even if they don't know it), so do shellfish farmers.

Unfortunately, despite the end-user and economic advantages offered by growing triploid oysters, shellfish farmers have noticed that triploids are more sensitive to environmental stress than their diploid counterparts, a vulnerability that is likely to intensify as the climate continues to change.

Having already experienced triploid losses in the past, many growers are hesitant to invest in triploids, leaving them caught between market demand and the potential economic losses from investing in a more fragile oyster. "Like many growers, we've seen triploid oysters struggle in recent years," says Joth Davis, owner of Baywater Shellfish. "We've had to reduce our reliance on them because of the mortality problems, even though we know they're a superior product in the marketplace. Under the right conditions, triploids grow faster and produce firmer, higher-quality meat, especially in summer when diploid oysters are focused on reproduction."

The first step in unlocking this bottleneck is to understand when, where, and under what conditions triploids are more likely to die. To do this, our science team—usually made up of UW researchers and undergraduates, including CICOES summer interns, NOAA Hollings scholars, and American Fisheries Society Hutton fellows—visits oyster farms across coastal Washington during every low tide cycle to check on their experimental oysters.

WHERE MUD MEETS MICROSCOPE

Thanks to the peculiarities of the seasonal rhythm of low tides in Puget Sound, in addition to working in the

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Photo: Craig Norrie

UW researcher Craig Norrie conducting night-time fieldwork

dead of night in fall and winter, we need to work in the middle of the day in the spring and summer. Working year-round in the mud and enduring beating sunshine and freezing cold, we monitor survival and growth, download data from sensors that log environmental conditions, and collect oysters to go back to the lab for physiological tests. This often involves navigating the stench of dead and rotting oysters that have succumbed to summer stress, scraping barnacles off oysters until hands ache, or outrunning a rapidly incoming tide. For students, this provides a crash course in applied marine science; for most, it's their first time experiencing this blend of research and industry collaboration and learning how academic science can directly support coastal communities.

The fieldwork aspect of this project shows us how farmed oysters perform under real-world conditions. This helps build hypotheses on what might be driving differences in sensitivity of triploid oysters. But to really pick apart how environmental stressors impact farmed oysters, we need to see how they react under controlled conditions. So, we select a few unlucky oysters to transport back to the UW campus for some laboratory stress trials.

Using a state-of-the-art system that allows the manipulation of multiple environmental parameters, oysters are subjected to a range of temperatures, pH, and dissolved oxygen levels. This allows us to understand how each of these parameters impacts oysters, both one factor at a time and multiple factors simultaneously. The simultaneous aspect is important because in the real world, multiple stressors are likely to occur at the same time. One example of this could be an upwelling event when cold, low-oxygen, high-acidity waters are brought to the surface from deep underwater. Or in a marine heatwave situation, increased temperatures may be accompanied by low dissolved oxygen levels.

Photos: Craig Norrie

Clockwise from upper left: Experimental tanks; one of our partners—Blue Dot Sea Farms, a subtidal (floating) farm that also grows seaweed; 2024 summer fieldwork crew

FAMILY MATTERS WHEN OYSTERS FACE STRESS

Together, the results of the lab and field experiments have shown that the sensitivity of triploids to environmental stress may be influenced more by their genetic background and method of production than by triploidy itself. The extra set of chromosomes in triploids can come from either the father (mated triploids) or from the mother (induced triploids). We found that oysters with similar genetic backgrounds tend to survive and grow more similarly under stress, while those from different genetic lines can show very different outcomes. This means that one potential solution to reducing triploid mortality is to broaden the genetic pool used in triploid production, and to selectively breed for traits that promote resilience.

In controlled laboratory experiments, mated triploids were generally more sensitive to lower pH levels, while field trials across sites such as Hood Head, Eld Inlet, and Clam Bay showed that performance varied widely, depending on both site conditions and genetic background. Even among diploids, oysters produced through different breeding methods showed distinct survival patterns, reinforcing that genetics play a major role in how oysters respond to temperature, oxygen, and acidity stress.

What really stood out from the lab experiments was how much variation we saw between oyster families. It's not just about being diploid or triploid; their genetic background and how they're produced seem to make a big difference in how they handle stress. Even within the same ploidy group, some oysters coped well under low oxygen or high carbon dioxide, while others didn't. That tells us that resilience isn't fixed; it's something we can select and build into future breeding lines. These findings suggest that breeding and site selection strategies tailored to local environmental conditions could be key to improving triploid survival under future ocean conditions.

HELPING OYSTER FARMERS MAKE DECISIONS

Finally, the most critical step of any applied research like this is getting results into the hands of people who will actually use them to improve decision-making and strengthen the long-term sustainability of the aquaculture industry in Washington and beyond. That meant finding a way to turn field data and laboratory experiments into something practical that growers could use on their farms. Our solution to this challenge is an online decision-support tool designed to help oyster farmers weigh the potential risks and rewards of growing triploids. It brings together results from this research and from other studies across the world to help growers make informed, science-backed choices.

> *"The goal is not to tell growers what to do, but to give them the information they need to decide for themselves and see how biology, environment, and management choices intersect."*

Through an interactive map and visualization platform, users can explore how temperature, site, and ploidy interact to shape survival and growth, or see how conditions at their own farm compare to the study sites. The goal is not to tell growers what to do, but to give them the information they need to decide for themselves and see how biology, environment, and management choices intersect. The tool reflects the idea that resilience in aquaculture starts with knowledge: understanding when and where triploids thrive and recognizing the environmental factors that might pose risks. By translating complex data into clear, usable insights, the tool helps bridge the gap between research and real-world decisions. It also stands as an example of what collaboration between scientists, industry partners, and growers can achieve: applied science that doesn't just describe problems but also offers solutions.

The next phase of the work will expand these models and integrate them with hatchery and breeding programs designed to strengthen long-term resilience. For growers, that means fewer losses and greater confidence in the face of extreme summers. For scientists, it shows how research can move beyond description to deliver solutions in real time. What began with muddy boots and late-night tides is now shaping how a vital coastal industry will adapt to a changing ocean. ■

POSTCARD FROM THE FIELD

Watching the Ice Break

Arctic AIR science team member Jiaxu Zhang (right) joined local collaborator Alex Whiting (left) and community member Tyler Kramer (middle) to test data collection in coastal waters. The goal is to monitor how river runoff raises the water level ("waterhead"), helping to block salty seawater from entering the inlet.

Photos: Courtesy of Jiaxu Zhang

—by Jiaxu Zhang, UW CICOES & NOAA PMEL

ARRIVAL IN KOTZEBUE

We arrived in Kotzebue, Alaska, on May 15, 2025, after a smooth transit flight from Anchorage. The Twin Otter was packed with instruments and, by late afternoon, we were already in the air again, performing calibration and collecting the first sample data over Kobuk Lake.

The next day, under calm skies, we carried out our first full mapping survey—flying low at 500 feet for the LATIS LIDAR and later climbing to 7,000 feet for the Pika-L hyperspectral camera. From above, the lake appeared frozen and bright, but subtle cracks and dark patches hinted that breakup would begin soon.

Watching the instruments record the data felt like seeing spring arrive in real time.

We came to Kotzebue to study how the lake ice evolves each year and how the timing of spring breakup affects the community. A rural Alaska Native village tucked against the Chukchi Sea on Alaska's west coast, Kotzebue has few roads leading away from it. It has no connections to the state's highways; residents instead rely on off-road transportation: ATVs in the summer and, in the winter, snowmobiles. When Kobuk Lake is frozen over, residents use snowmobiles to traverse it to reach subsistence fishing camps. But in recent years, as breakup has become increasingly unpredictable, residents have had a tougher go of it getting to those camps.

COMBINING MEASUREMENTS WITH OBSERVATIONS

Our goal was to combine airborne measurements with observations from local community members to better understand and model these changes.

Flying low over the beautiful white landscape was humbling. From above, the ice looked smooth, but the LIDAR revealed subtle ridges and pressure lines invisible to the eye. In some places, the surface darkened where river water flowed under the ice—a process nicknamed the "tea-bag effect," when tannin-rich meltwater from tundra and wetlands spreads across the surface like brown ink. These areas absorb more sunlight, accelerating melt and signaling where the first open water will form.

Not every day allowed flying. Fog and low clouds often grounded us for hours, sometimes for days. During those times, we checked instruments, reviewed flight tracks, visited the radio station, and shared updates with the environmental office. I liked those small moments: explaining our work, hearing stories, and feeling part of the community.

One moment that has stayed with me came through our local collaborator, Alex Whiting, who was in regular contact with Kotzebue Elder Bobby Schaeffer. After one flight, we showed Alex our aerial map of a long ice ridge crossing the lake. He later told us that Bobby had recognized it immediately—it's a feature he has seen every spring since childhood, marking a weak point in the ice that usually opens first. Hearing about that connection gave new meaning to our data. It reminded me that every line on a map represents a place people know personally.

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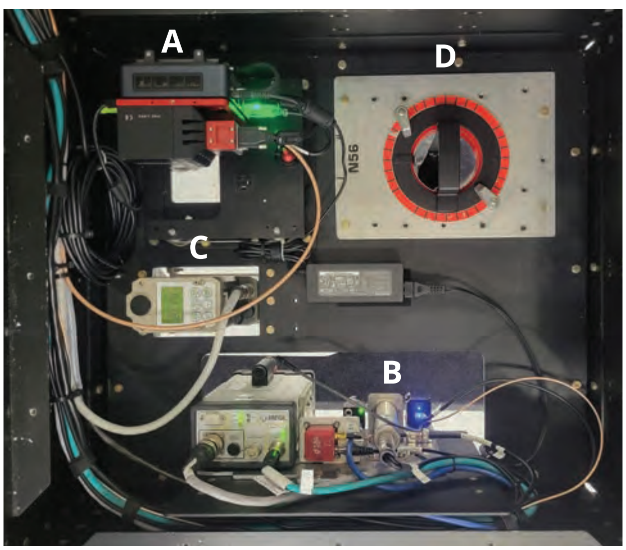
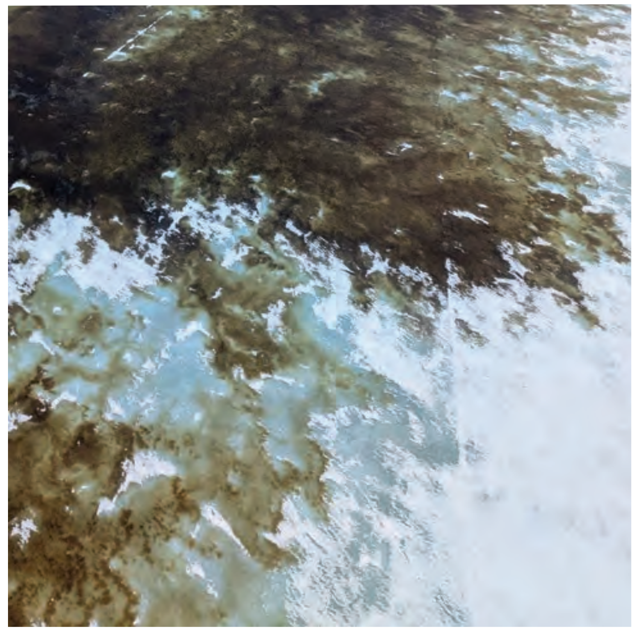


Instrument bay of the NOAA Twin Otter used in the Arctic AIR mission. The setup includes: (A) the Pika L hyperspectral camera for surface color and reflectance measurements; (B) the integrated LATIS system for LIDAR and sea-surface temperature sensing; and (C) a downward-looking radiometer that measures emitted infrared radiation. A GoPro camera (D) facing backward can be used for buoy deployment recordings.



Photos: Courtesy of Jiaxu Zhang

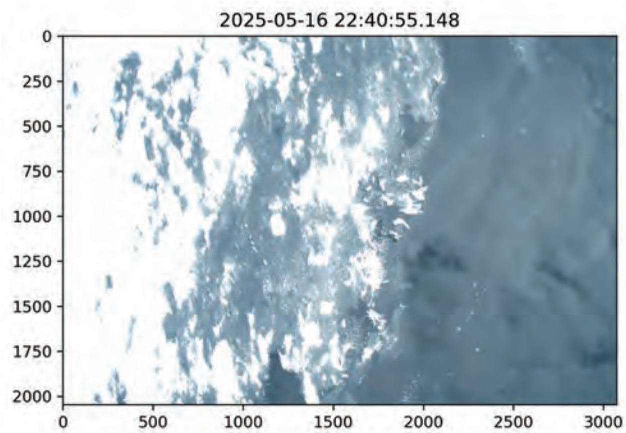
top to bottom: Brown-colored river water entering Kobuk Lake, contributing to coastal ice melt. This so-called "tea-bag effect" is caused by dissolved organic matter (particularly tannins) from decaying vegetation and peat in surrounding tundra and wetland soils. Previous snowmobile tracks can still be seen on the ice.

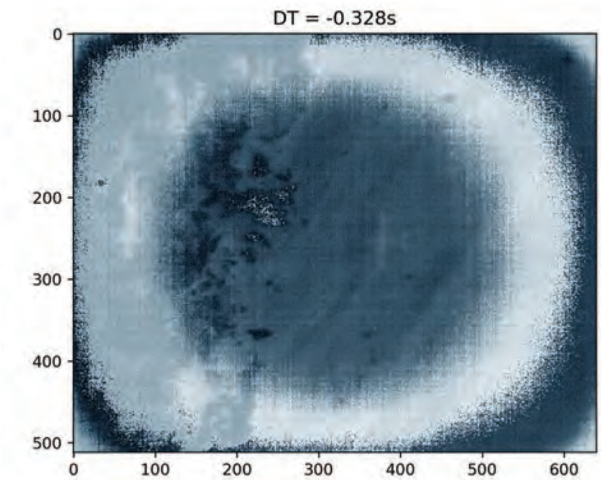
Bobby Schaeffer, a Kotzebue elder, shared his intimate knowledge of Kobuk Lake with the Arctic AIR science team, and he further participated in the project by conducting ice thickness measurements in northeastern Kobuk Lake.

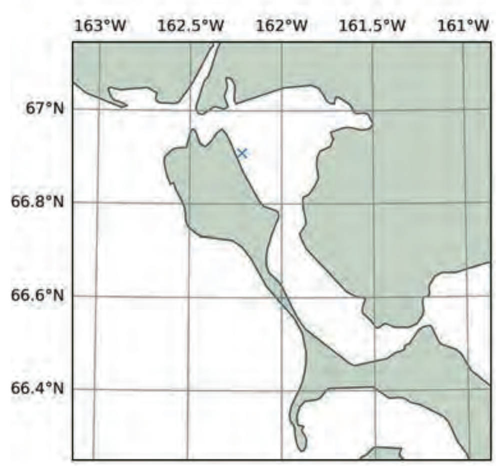
When the flights ended, we had mapped Kobuk Lake four times, deployed four buoys over the open ocean farther south, and collected hours of hyperspectral imagery. But what stayed with me most was not just the data, it was also the teamwork, the patience in the cold, and the generosity of people in Kotzebue who shared their knowledge and hospitality.

As we took off for the last time, the lake below looked different: the cracks wider, the snow thinner, a darker color spreading from the inlet. The Arctic summer was coming. ■

The Arctic AIR program, led by NOAA's Pacific Marine Environmental Laboratory in collaboration with the University of Washington's Cooperative Institute for Climate, Ocean, and Ecosystem Studies, the Alaska Ocean Observing System, and the Department of Energy, conducts airborne surveys over Alaska waters to study physical and biological interactions and their impacts on marine ecosystems and coastal communities. The 2025 fieldwork described in this article was supported by NOAA's Arctic Research Program and focuses on understanding and predicting ice-breakup timing in Kobuk Lake for the Kotzebue community.







Sample data from the LATIS (LIDAR and SST) system collected over Kobuk Lake on May 16, 2025. The visible (above left) and infrared (above) images show the ice-water boundary during the early breakup phase, as the aircraft flew from right to left over the image. The map (left) marks the flight location (water is white; land is green). Together, these observations help identify where melting first occurs along the ice edge.

“As we took off for the last time, the lake below looked different: the cracks wider, the snow thinner, a darker color spreading from the inlet. The Arctic summer was coming.”

Workshop on Polar Winter Climate

—by Varunesh Chandra, UW CICOES

I participated in the Workshop on Polar Winter Climate, held at the British Antarctic Survey in Cambridge, UK on April 23–25, 2025. This event brought together leading scientists from across the globe, including experts from North America, Europe, Asia, and the Southern Hemisphere who work on polar climate processes, stratosphere–troposphere coupling, and the influence of the poles on global weather extremes. It was a privilege to represent CICOES and NOAA-PMEL at such a high-level international forum.

I delivered an invited presentation titled "Dynamics of High-Latitude Atmospheric Blocking and Teleconnections to North American Winter Extremes," which highlighted the innovative work being done at CICOES on Arctic–midlatitude connections. Sharing our research on this stage not only enhanced international visibility for CICOES, but also sparked meaningful discussions with senior scientists working on related challenges.

The workshop was deeply enriching. I gained new insights into cutting-edge diagnostic tools, including advanced wave-activity flux methods, potential-vorticity-based blocking techniques, and emerging approaches for analyzing polar vortex geometry. These methods directly strengthen our analytical capabilities at CICOES and will support improvements in our ongoing Arctic research projects.

Equally valuable were the global collaborations that emerged from this opportunity. I established connections with scientists from leading institutions around the world, opening doors for joint analyses, comparative modeling studies, and future proposal partnerships. These collaborative relationships broaden the reach of CICOES and ensure we remain actively engaged in international efforts to understand rapid polar change.

Overall, this experience significantly enhanced my scientific skillset, expanded CICOES's global visibility, and strengthened our network of international collaborators. It also supported my professional growth by improving my ability to communicate complex climate dynamics to both scientific and interdisciplinary audiences. I am grateful for the opportunity to contribute to CICOES's mission and to bring new tools and insights back to our research community. ■

Photo: Courtesy of Varunesh Chandra

Postdoctoral researcher Varunesh Chandra attended the Workshop on Polar Winter Climate with support from the CICOES Professional Development Program.

ONE HALF CENTURY OF

Photo: Elizabeth McHuron, NMFS Permits 16058 and 22678

California Sea Lion Data

UNDERPINS PREDICTIVE MODELS FOR MANAGEMENT DECISION-MAKING

—by Elizabeth McHuron, UW CICOES, with contributions from Sharon Melin, NOAA Alaska Fisheries Science Center

above: California sea lion pup

SAN MIGUEL ISLAND

Perched atop a cliff, on an island less than 30 miles from the southern California coast, sits a small unassuming research station that—on a clear day—boasts million-dollar views of white sandy beaches, sparkling blue waters, and magnificent sunsets. While San Miguel Island is not physically far from one of the world's most iconic metropolises, it is a world away from the traffic, lights, and sunny weather of the City of Angels. There is no running water, and instead of car horns, the sounds of barking sea lions can be heard from the research station overlooking the western tip of the island that is home to one of the world's largest California sea lion colonies.

Human visitors to the island are few and far between. The most consistent presence comes from visitors to the Channel Islands National Park and a small group of researchers from the Marine Mammal Laboratory at NOAA's Alaska Fisheries Science Center in Seattle. The researchers spend much of their time counting, weighing, and marking California sea lions and some of the other four seal and sea lion species that breed on the island. Their efforts have generated nearly a half-century of California sea lion data spanning numerous El Niño events and the infamous "Blob" that brought extremely warm sea surface temperatures to much of the North Pacific Ocean.

Now, under shifting federal research priorities, the fate of these long-term sea lion datasets hangs in the balance. These shifts have been the impetus for a new collaborative effort among researchers at CICOES and the Marine Mammal Lab's California Current Ecosystem Program. Together, we are developing predictive tools to help mitigate the potential loss of further data collection while also informing cost-effective sampling strategies to maintain this valuable timeseries.

LEARNING FROM THE PAST TO PREDICT THE FUTURE

Long-term ecological datasets, such as the ones collected on San Miguel Island, are invaluable for understanding how ongoing and future environmental changes will impact individual species, communities, and entire ecosystems. In the California Current Ecosystem, which includes nearly 3,000 km of waters from Baja California to southern British Columbia, California sea lions are considered ecosystem indicators because they respond rapidly to environmental changes, such as increases in ocean temperatures that can affect food availability or the production of algal toxins that can result in mortality. California sea lions are also one of the most visible and charismatic reminders of ocean conditions along the US west coast, as starving or sick sea lions often become stranded on very public shores. Stranded animals are a potential public health risk because of zoonotic diseases, and they also can strain limited resources of rehabilitation facilities that care for them.

Our goal is to build upon existing knowledge that, simply put, warm years produce small pups, presumably because their moms have a harder time finding food. This has cascading effects because starving pups tend to strand more during these years and survival rates tend to be lower. For example, during one of the very warm years of the "Blob," only 11% of pups born were estimated to survive to their first birthday when pups grew very little and were 3–5 kg lighter than the long-term average. We plan to explore how well we can predict the weight of sea lion pups in the fall and their growth rates in late fall/early winter using just measurements of sea surface temperatures within foraging areas, and whether considering other factors, such as upwelling indices or sea lion diets, markedly improves our predictive ability.

—continued on page 16

Colony of California sea lions on San Miguel Island, which is located within the California Current Ecosystem

Photo: NOAA Alaska Fisheries Science Center, NMFS Permits 16058 and 22678

Illustration: iStockphoto.com: PeterHermesFurian

Illustration: NOAA Alaska Fisheries Science Center

Preliminary results indicate that sea surface temperature alone does a reasonably good job in predicting both pup mass and growth rates in many years. For example, models successfully predicted 40% of the years when pup masses fell below thresholds associated with above-average strandings of sea lion pups. Most additional metrics added little in terms of predictive ability, with the exception of sea lion diets that help explain why pups in some years are larger or smaller than expected based on sea surface temperatures alone. This comes at a trade-off though. While considering diets increases our ability to predict years with anomalously low pup masses (from 40% to nearly 70% for some prey species), it also results in more ”false alarms” or years in which models predict pup masses should be anomalously low but are not. This raises the question of whether, from a management or economic perspective, it is worse to be unprepared for something that eventually happens or to prepare for an event that never materializes.

OTHER VALUES OF LONG-TERM DATASETS

Research programs that generate long-term ecological datasets help train the next generation of scientists, extending their value well beyond their current ability to understand ecological processes and inform management decisions. Training can come through a variety of mechanisms, including use in undergraduate classrooms, as sources for theses and dissertations, and through hands-on training in the field. For example, several projects within the CICOES undergraduate internship program have involved long-term datasets on salmon and groundfish in Alaska.

I have first-hand experience with these benefits, having traveled to San Miguel Island in 2013 as a (somewhat) young PhD student. I spent more than a week studying moms and their pups at the tail-end of an unexplainably (still!) poor year. This was my first foray into the sea lion world, but certainly not my last. It provided the experience I needed to complete my PhD on California sea lions and created collaborative opportunities that have helped shape the trajectory of my career. I am just one of the numerous interns, volunteers, and students who have experienced the magic that is San Miguel Island; we each carry a small piece of the institutional knowledge from NOAA researchers, which is so vital for marine mammal research.

***Photo:** NOAA Alaska Fisheries Science Center, NMFS Permits 16058 and 22678*

Sea lions and elephant seals congregate on San Miguel Island at sunset.

BRIDGING THE GAP

The ability to predict the mass and growth rates of California sea lion pups, based on sea surface temperatures—albeit imperfectly—helps provide an early warning of conditions in the California Current Ecosystem to state and federal managers and other interested stakeholders, as well as valuable information for stranding centers to anticipate and coordinate responses to large stranding events of emaciated sea lion pups. We can forecast these predictions months in advance because of the existence of regional ocean models that simulate ocean temperatures and other physical and biogeochemical conditions. For example, a suite of new regional ocean models developed under NOAA’s Changing Ecosystems and Fisheries Initiative aims to provide high-resolution past and future conditions across large swaths of the Atlantic, Pacific, and Arctic Oceans. While our focus is on a breeding rookery in southern California, results have ramifications for the entire California Current Ecosystem because California sea lions are wide-ranging within this ecosystem throughout the year, and changes in pup growth and survival that help drive population dynamics are connected to local ecosystem processes.

Long-term ecological datasets are, by definition, collected regularly and continuously. This regularity can be difficult to maintain due to the need for consistent support, in addition to unexpected events that may derail data collection. For example, California sea lion pups had been weighed annually from 1975 until 2020, when the COVID-19 pandemic resulted in the cancellation of fieldwork. Similarly, weather and funding delays in 2024 resulted in cancellation of the fall field season. Predictions from our models indicate that neither 2020 nor 2024 had a high probability of being poor years for sea lions, which is consistent with anecdotal observations that eight-month-old pups in the 2024 cohort were in good body condition.

Predictions cannot replace the need for ongoing data collection, crucial for validating and improving the accuracy of forecasts. They can help bridge the gap when annual data collection is not possible, as was the case in 2020 and 2024. Forecasts can identify years when it may be important to prioritize data collection, such as average sea surface temperature years when models struggle to accurately predict pup masses. Combining regular annual predictions with less frequent field sampling provides a path forward to help maintain this valuable long-term dataset under a shifting landscape of research and funding priorities. ■

> *“Predictions cannot replace the need for ongoing data collection, crucial for validating and improving the accuracy of forecasts.”*

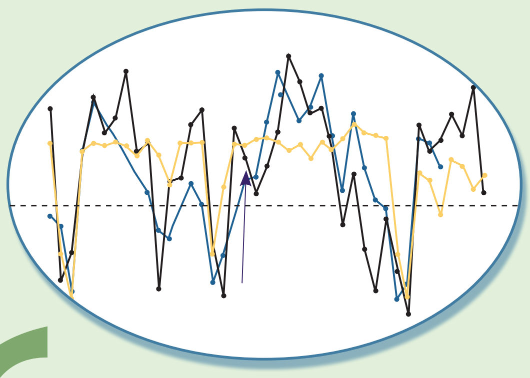
DEVELOPING A PREDICTION FRAMEWORK

50 years of hands-on measurements of sea lion pups...

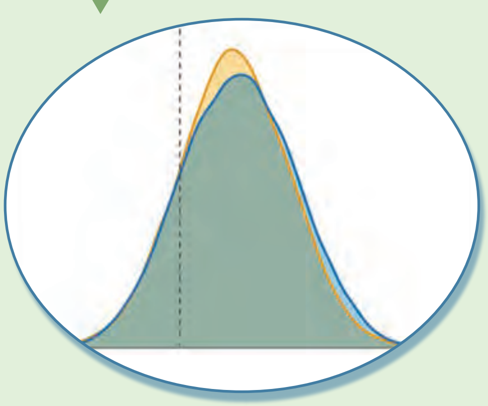
Photo: NOAA Alaska Fisheries Science Center, NMFS Permits 16058 and 2267

provides the raw data to build a prediction tool...

that can be validated by real-world observation...



which can then be used to make forecasts for future years (or hind-casts for prior years without data).



CHANGING ECOSYSTEMS
AND THE FUTURE OF

Alaskan Crab Fisheries

UNDERSTANDING THE ROLE OF UNCERTAINTY

How Ocean Acidification and Warming Could Reshape a Vital Industry

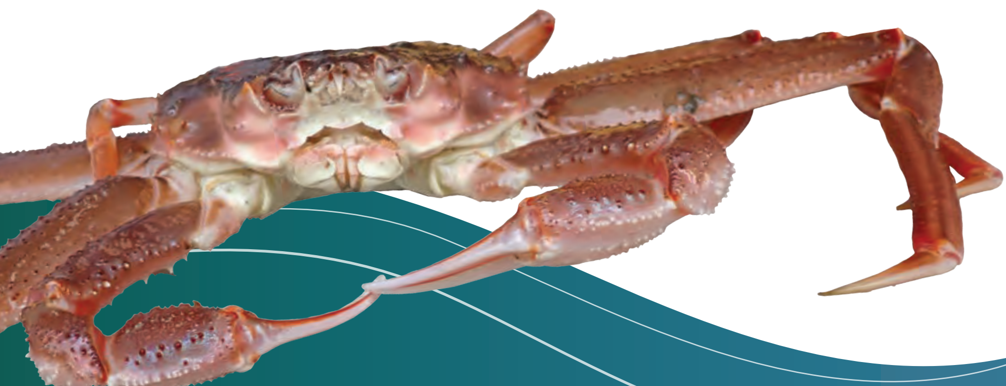
—by **Heather Nibert,**
UW School of Aquatic & Fishery Sciences

WHEN THE FORECAST LOOKS CLOUDY

In the icy waters of Alaska, red king crab and southern Tanner crab scuttle through an uncertain future. The ocean around them is warming and turning more acidic, making it harder for these crabs to survive and grow. Every shift in their world sends ripples through the ecosystem and the fishing communities that depend on them.

Predicting how these crab populations will change in a warming and acidifying ocean is no simple task. Scientists must estimate how many crabs survive each year and how environmental shifts will affect their growth, but those predictions are never entirely certain. Consider the weather: if the forecast says there is an 80 percent chance of rain, most people grab an umbrella. But if that chance drops to 20 percent, many take the risk of leaving it behind. That same logic guides fisheries scientists when they provide information on the long-term prospects for how much crab can be safely caught each year. When uncertainty about crab survival and growth rises, scientists must weigh how confident they are in their forecasts before this information can be used to advise on fishing limits that affect both the ocean and coastal communities.

Forecasting crab populations is not just about knowing what might happen, it is about understanding how sure we can be. For managers, the difference between 80 percent certainty and 20 percent can mean the difference between stable livelihoods and ecosystem stress, between a thriving community and one left in the rain.



above: Red king crab
left: Tanner crab
Photos: NOAA Fisheries

BEHIND THE SCREENS: WHAT MODELING REALLY LOOKS LIKE

Understanding how scientists identify and measure uncertainty requires looking behind the screens where these forecasts are built. At first glance, modeling how climate affects fisheries might sound like solitary, computer-heavy work. And it is, but it is also profoundly collaborative. In a study published in September 2025, researchers at the University of Washington and NOAA Fisheries worked together across disciplines using advanced numerical models to simulate how climate change will affect the two species of crab in the Bering Sea ecosystem.

"This research is part of the Alaskan Climate Integrated Modeling (ACLIM) project, a long-term effort that brings together oceanographers, marine ecosystem modelers, and fisheries scientists to understand how environmental change will shape Alaska's marine resources, from fish to crab," said Kirstin Holsman, research fishery biologist at NOAA's Alaska Fisheries Science Center. "ACLIM builds on projections from high-resolution regionally downscaled global Earth System Models, using them as the foundation for detailed regional simulations of the Bering Sea."

Earth System Models, developed by modeling centers around the world, simulate how greenhouse gases and aerosols interact with the ocean and atmosphere through interconnected physical and biogeochemical processes. These models simulate how ocean conditions may change over the next century, including processes such as ocean acidification, which is a key focus of the NOAA Ocean Acidification Program.

"Global Earth System Models provide a big-picture forecast," said Wei Cheng, research oceanographer at the University of Washington, "but they are too coarse to capture the fine details that matter for Alaskan crab. So, we have to dig a little deeper."

The team "downscales" the global Earth System Model projections to the regional level using a fine-resolution ocean hydrodynamical model. This turns a blurry global picture into a sharper view that reveals key regional features, such as the Cold Pool, a large mass of cold water that forms on the bottom of the Eastern Bering Sea shelf each summer. Just as the Cold Pool affects distribution of commercially important fish species, ocean temperature change and acidification determine where crabs live and how they grow.

The refined regional ocean conditions are then provided to marine ecosystem modelers and fisheries biologists to develop bio-economic models. These models lay the groundwork for the next step: connecting environmental change to the biology of crab and, ultimately, to the economics of the fishery.

LINKING ENVIRONMENT, BIOLOGY, AND ECONOMICS

To explore how environmental changes impact living resources, researchers use bio-economic models that link ecosystem dynamics to economic outcomes. "Bio-economic models link the effects of ocean acidification, through population dynamics, to impacts on fisheries," said Michael Dalton, economist at NOAA's Alaska Fisheries Science Center. "It's a multi-level model that takes you from egg production all the way to economic output."

The bio-economic model used by the University of Washington and NOAA scientists is built using data from laboratory experiments on the effects of

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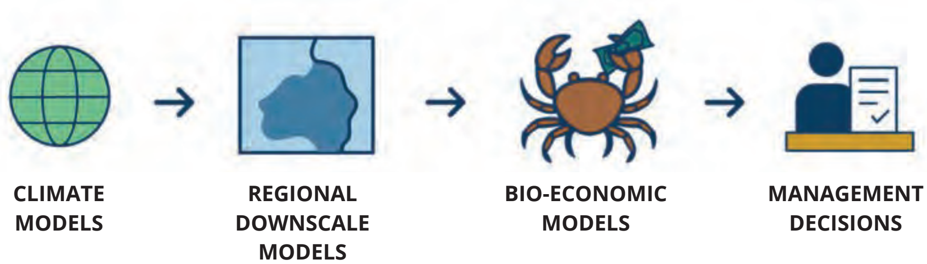


An integrated modeling framework linking global climate projections to fisheries management. Climate models feed into a regional downscaling model that captures key features such as the Bering Sea Cold Pool. These outputs inform biological models for Alaskan crab species, which in turn support management decisions under changing ocean conditions.

changing acidity on larval and juvenile crab, and from research surveys in the Bering Sea, as well as from data on costs and prices from fishers.

Using this information, the bio-economic model determines the impacts of harvest rates on crab populations, which then allows the economic model to calculate optimal fishing levels that maximize profits while sustaining populations.

The model produces output data that can be visualized as graphs, which show how removing individual sources of uncertainty reduces the spread of the projected survival trajectories. For example, omitting uncertainty related to ocean acidity effects on juvenile or larval stages narrows the range of outcomes, revealing that these effects contribute most to overall uncertainty. These visualizations help clarify where uncertainty is concentrated for each species and indicate which data or experiments would most improve future model performance and the reliability of management advice.

THE IMPORTANCE OF UNCERTAINTY

Uncertainty in science is often seen as a problem, but here it serves as a guide. If we know where the largest uncertainties lie, we can target research efforts to reduce them and improve management decisions.

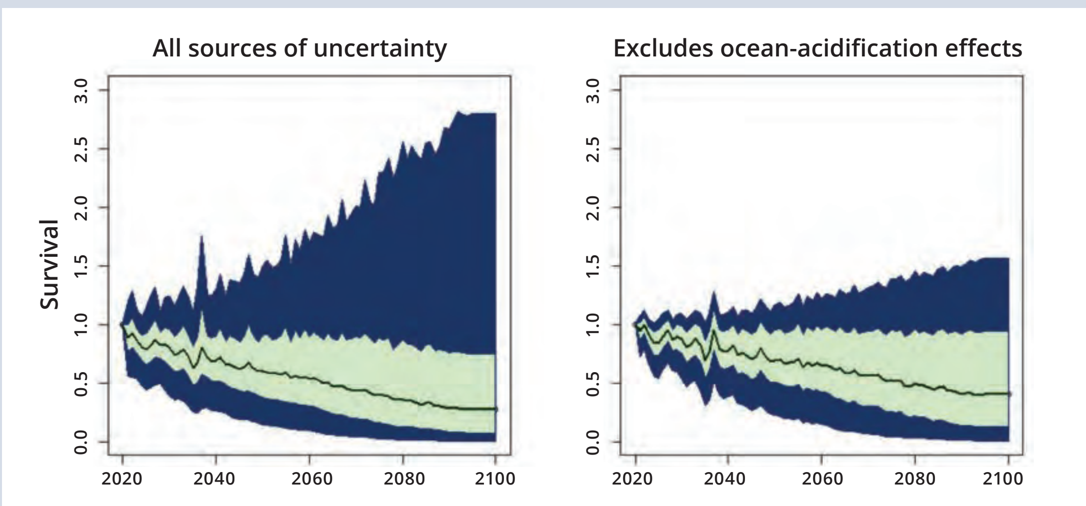
"A decade ago, we had only used one Earth System Model, so this uncertainty could not be accounted for," said André Punt, lead study author and population ecologist at the University of Washington. "But now, as we develop end-to-end modeling frameworks, we are finding that not only are the bio-economic models themselves uncertain, but the predicted values and expected trends of climate variables also vary."

Every step in this process brings a different kind of uncertainty, such as:

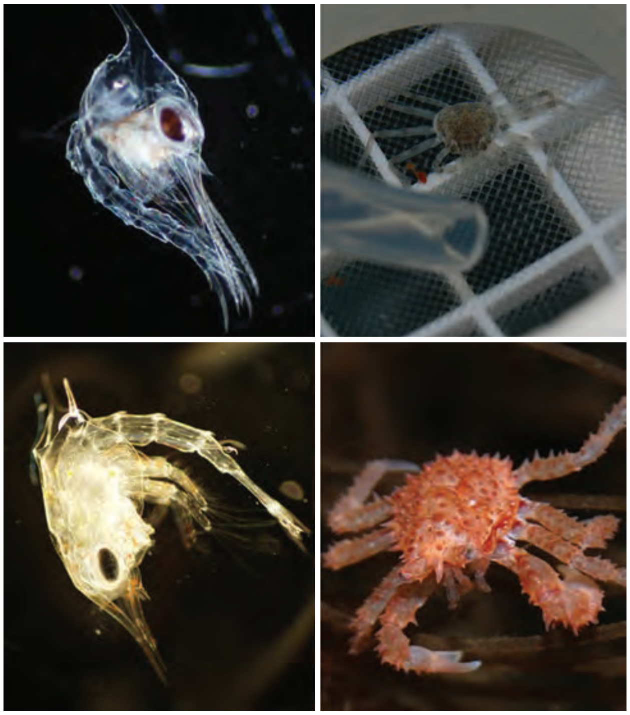
- **Scenario uncertainty:** We do not know what choices people will make about burning fossil fuels in the future.
- **Structural uncertainty:** Each model is built slightly differently and makes different assumptions about how the ocean, crab stocks, and fisheries behave.
- **Intrinsic uncertainty:** Nature itself is chaotic. Tiny changes can grow into major differences, much like the "butterfly effect" in weather forecasting.

These uncertainties do not make prediction impossible, but they do make humility essential. "We are always balancing what we know, what we can estimate, and what remains unknowable," said Albert Hermann, CICOES research scientist.

TANNER CRAB SURVIVAL PROJECTIONS



Southern Tanner crab survival projections. left: Full model including all sources of uncertainty. right: Removing uncertainty from ocean-acidification effects on larval stages narrows the projected survival range, highlighting the importance of early-life processes in driving forecast uncertainty.



Photos: NOAA Fisheries/Chris Long

top row: Larval and juvenile Tanner crab; bottom row: Larval and juvenile red king crab

The largest uncertainties arise from differences among the Earth System Models and emissions scenarios. Additional uncertainty stems from incomplete understanding of how ocean acidity and temperature affect early-life survival and growth. Economic factors, including how fishing costs and market prices respond to changes in catch, also contribute to overall uncertainty. By clarifying the gaps in current knowledge, scientists can focus new studies on the questions that most improve crab forecasts.

A PATH FORWARD FOR RESEARCH AND MANAGEMENT

Future research that explores how varying levels of ocean acidity and temperature affect crab biology will be most beneficial for increasing our understanding of the long-term effects of climate on crab populations. For example, expanding the range of acidity tested for red king crab larvae and increasing sample sizes for southern Tanner crab juveniles will help reduce uncertainty.

The study also highlights the need to consider life stage-specific impacts, such as juvenile growth for red king crab and larval survival for southern Tanner crab. These insights will help scientists and managers plan future ocean acidification experiments and decide where to spend limited research funding most effectively.

WHY THIS MATTERS

These scientific insights matter far beyond the lab. For many Alaskan coastal towns, crab fishing is more than an industry; it is the backbone of local economies and family livelihoods. Reducing uncertainty in crab forecasts helps these communities plan for the future, adapt to changing conditions, and sustain their way of life in a changing ocean.

As temperature change and ocean acidification reshape the Bering Sea, research that quantifies uncertainty and integrates knowledge across disciplines gives managers stronger tools to set sustainable harvest limits, protecting both crab populations and the communities that depend on them.

By linking environmental, biological, and economic uncertainty to real-world management decisions, this study provides a roadmap for effective management strategies and more resilient fisheries. Prioritizing the experiments and data that most improve predictions helps managers make confident, cost-effective, and climate-informed choices, whether that means taking the "umbrella" or leaving it behind. ■

Photo: Heather Nibert

André Punt, population ecologist at the University of Washington

Photo: University of Washington

Qiuxian Li with Dubs, the UW mascot

JOURNEY IN CLIMATE SCIENCE

—by Qiuxian Li, Postdoc

When I arrived in Seattle in the fall of 2023, the city's gray skies felt both foreign and exciting. It was my first time living abroad, and everything felt new: the people, the language, and the steady rain and cloudy weather of the temperate oceanic climate. As I would soon realize, those clouds above Seattle were more than just scenery; they were central to my research.

Over two years as a postdoctoral scholar at CICOES, I explored how clouds, ocean heat transport, and atmospheric feedback interact to shape Earth's climate. Working with mentors Wei Cheng, Kyle Armour, and LuAnne Thompson, I completed four interconnected projects that advanced understanding of global climate sensitivity, which refers to how much the Earth will warm if carbon dioxide levels double.

Project 1: What Truly Controls Ocean Heat Transport

The first project began with the very first meeting with my mentors. I still remember that afternoon in LuAnne's office, my first real scientific conversation after arriving in Seattle. We talked about my PhD work, where I had used a new set of climate experiments to separate the contribution of ocean circulation changes to the ocean temperature response under global warming. After listening carefully, Kyle made a comment that led me in a new direction. He said, "This framework might also help us decompose ocean heat transport changes toward the poles."

There has been a long-standing debate in the literature about whether changes in ocean circulation or temperature dominate the changes in poleward ocean heat transport—the process by which seawater carries heat from warmer regions (like the tropics) to colder regions (like the poles). Much of this disagreement comes from differences in how researchers separate these two effects. In many earlier studies, the estimated contribution from temperature changes actually included part of the circulation effect, making it difficult to distinguish between the two.

Through a set of new analyses, I was able to isolate the portion of temperature change not influenced by circulation changes, more accurately quantifying its contribution to ocean heat transport. The results showed that previous methods tended to overestimate the role of circulation changes, suggesting that temperature-driven effects are more important than previously thought.

Project 2: How Tropical Clouds Shape Arctic Warming

At the same time, I began participating in a larger project led by Wei Cheng that explores how cloud feedback influences climate sensitivity. Clouds can act like a mirror or a blanket, reflecting sunlight or trapping heat. Cloud feedback refers to how clouds change in response to warming, either amplifying the warming (positive feedback) or dampening it (negative feedback). This project involved cloud-locking experiments, where we allowed everything in the climate model to change except the radiative properties of clouds in order to isolate their influence. These experiments had been completed by scientists from NOAA's Pacific Marine Environmental Laboratory and the Department of Energy's Pacific Northwest National Laboratory.

As I started analyzing the results, I was surprised by how strongly clouds outside the polar regions, particularly in the tropics, affected polar temperatures. Changes in tropical clouds altered how much heat was transported through the atmosphere toward the poles, which in turn impacted Arctic warming. This was when I truly began to appreciate the interconnected nature of Earth's climate system.

Project 3: A Colder Start, a Warmer Future

After finishing the second project, I went through a short period of uncertainty. I wasn't sure what to do next. Then another CICOES scientist, Jiaxu Zhang, invited me to analyze a set of experiments she had completed. These experiments examined how different strengths of ocean heat transport influence global climate. That conversation opened the door to my third project.

> *"Clouds can act like a mirror or a blanket, reflecting sunlight or trapping heat."*

During our discussions, Kyle noticed that the difference between two experiments closely matched the difference between observations and model simulations. This meant we could use the experiments to understand not only how ocean heat transport shapes climate, but also how model biases can affect climate sensitivity.

We discovered something interesting: when ocean heat transport was weaker, the climate became cooler, especially in polar regions. But under greenhouse gas warming, these cooler climates warmed more strongly. The reason is simple yet powerful: weaker poleward ocean heat transport allows more sea ice to exist, which amplifies warming through albedo feedback—when more sea ice exists, more of it melts during warming, exposing darker ocean surfaces that absorb more sunlight and further amplify warming. This project deepened my understanding of how the mean-state ocean, meaning the background ocean temperature and circulation patterns that exist before any external forcing is applied, can shape not only today's climate but also its sensitivity to future warming.

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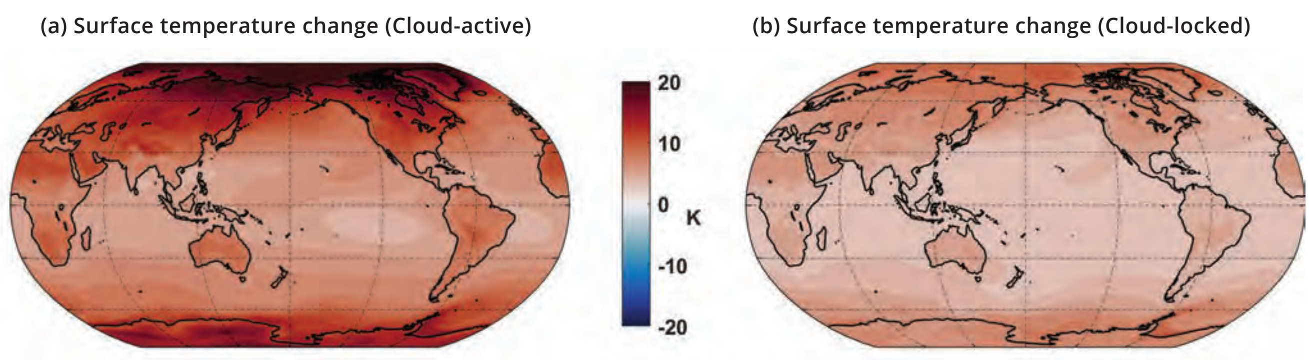

Changes in surface temperature (K) in response to 4 x CO_2 in cloud-active (a) and cloud-locked (b) simulations

Project 4: The Trouble with Two Rain Belts

The idea for my final project came up during one of our weekly discussions. Since we had seen how mean-state ocean conditions influence the climate's response to external forcing, we began to wonder whether other persistent model biases could also affect climate sensitivity. That was when LuAnne brought up the double ITCZ bias, one of the most common and stubborn climate model errors. In the real world, most tropical rainfall happens in a single band just north of the equator, known as the Intertropical Convergence Zone (ITCZ). But many climate models make a common mistake: they produce two such rain bands, one on each side of the equator.

To test how this bias might influence the climate, we designed a set of experiments that artificially forced the ITCZ to move southward, mimicking the double ITCZ pattern commonly seen in models. We found that when an ITCZ forms in the Southern Hemisphere, subtropical low clouds in the southeast Pacific decrease significantly. This region's cloud feedback turned out to be crucial; it controls how the Southern Ocean and the tropics interact and also influences the global surface temperature response.

MOVING FORWARD

Through these projects, I began to see a common thread running through my work, a single question that ties everything together: what sets Earth's temperature response to carbon dioxide increases? Different climate models give varying answers. Through the four projects I completed during my postdoc, we gained some important clues. One key source of uncertainty lies in cloud feedback, which varies widely among models. Another comes from mean-state biases, including how models underestimate ocean heat transport and long-standing issues such as the double ITCZ in the tropics. Each project has helped me see a different piece of this puzzle.

As I move forward, I hope to keep exploring this question, to better understand the physical processes behind climate sensitivity, and to bring us one step closer to answering how our planet will respond to human influence.

Looking back, I realize that all four of my projects were born and completed through collaboration. Each one began with a conversation. Working closely with my mentors and collaborators taught me not only how to design experiments and interpret results, but also how science grows through teamwork and curiosity. ▪

Photo: Courtesy of Qiuxian Li

Author Qiuxian Li (far right) with her mentors, Kyle Armour (far left), LuAnne Thompson (middle left), and Wei Cheng (middle right)

POSTDOC
EXPERIENCE

Photo: Joe Selmont

Matt Luongo (left) and Dave Bonan (right)

UNCOVERING THE DRIVERS OF

Recent Southern Ocean Cooling

—by Dave Bonan and Matt Luongo, UW CICOES

A CHALLENGING REGION

The Southern Ocean plays a central role in regulating Earth's climate under global change. It absorbs roughly 75% of the excess heat and about half of the excess carbon taken up by the global ocean, making it one of the most important buffers against climate change. How the Southern Ocean responds to continued anthropogenic greenhouse-gas emissions will shape future global projections of surface temperature, precipitation, and sea level rise: essential information for preparing for and adapting to a warming world.

However, because the Southern Ocean is vast, remote, and sparsely observed, we must rely heavily on climate model simulations to study its behavior. Confidence in future climate projections depends on the ability of climate models to reproduce the recent historical record, but the Southern Ocean remains one of the most challenging regions to represent in climate models.

While most of the planet has warmed since the start of the satellite era (~1980), the surface waters around coastal Antarctica and throughout much of the Southern Ocean instead show a broad cooling. Satellite measurements also indicate an increase in sea ice concentration that accompanies this cooling.

Most climate models, however, show little to no cooling, with many simulating strong warming and declining sea ice. This mismatch suggests that climate models may be missing key processes that shape the Southern Ocean's response to climate change—a knowledge gap that captured our attention and inspired our research. Answering the question "Why do nearly all climate models struggle to capture recent Southern Ocean temperature trends?" requires expertise across oceanography, atmospheric science, and cryospheric processes. This makes it well suited to the collaborative research environment at CICOES.

PRESENT-DAY OCEAN STRATIFICATION: AN OVERLOOKED FACTOR

Persistent biases in climate models of the Southern Ocean, together with the complexity of interacting atmosphere, ice, and ocean processes, make it challenging to identify which mechanisms drive the

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observed changes. Many explanations have been proposed: wind changes linked to historical ozone depletion, freshening from Antarctic ice melt, shifts in precipitation, changes in the sea-ice hydrologic cycle, and natural variability in deep ocean convection that most climate models do not resolve. Although each process may contribute to surface cooling, none fully explains why climate models fail to reproduce the observed cooling trend or how to reconcile that trend with simultaneous subsurface warming and evolving salinity.

One possible explanation that has received growing attention is ocean stratification, which refers to the vertical layering of seawater density set by temperature and salinity, and can alter how the ocean and atmosphere interact with each other. The influence of changes in ocean stratification on predictions of long-term Southern Ocean climate trends is still not well understood.

As CICOES postdoctoral fellows working with colleagues from UW and the NOAA Pacific Marine Environmental Laboratory, including Wei Cheng, Gregory Johnson, David Battisti, and Kyle Armour, we are leading complementary efforts to evaluate whether a more realistic representation of Southern Ocean stratification improves climate models' simulation of historical temperature trends.

IN SEARCH OF THE MISSING COOLING

One part of our work focuses on evaluating the representation of the Southern Ocean across different phases of the Coupled Model Intercomparison Project (CMIP). Climate models participating in CMIP apply the same physical laws, but differ in how they represent key processes. By comparing the simulations of historical climate change, we are able to identify systematic patterns, biases, and points of divergence from observations.

In these simulations, we are examining how heat enters, exits, and is redistributed within the upper ocean, decomposing the surface heat budget into its major components, including solar absorption, long-wave emission, latent and sensible heat exchange, and heat transport from winds and mixing. Comparing these processes between climate models and observations reveals where climate models allow too much heat in, mix heat too efficiently downward, or misrepresent atmospheric controls on surface energy

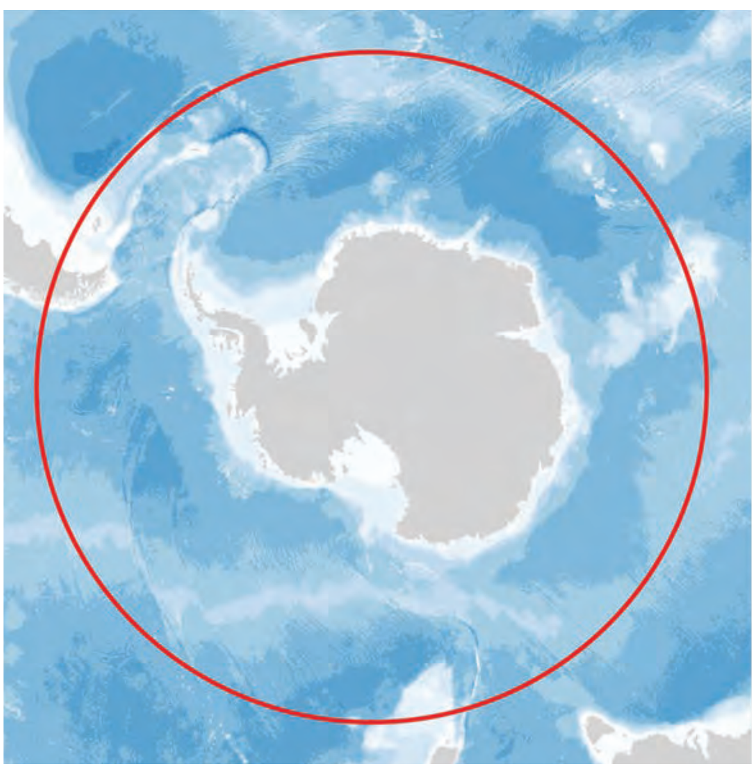

Illustration of the Southern Ocean, with ocean bathymetry shown in shades of blue (the darker the blue, the deeper the water) and land shown in light gray. The red circle marks the 50°S latitude band. Since the late 1970s, the region within this circle has exhibited little to no warming, with pronounced surface cooling in parts of the Pacific sector.

Massive iceberg floating in the Southern Ocean in Antarctica in a storm

Photo: iStockphoto.com: Ray Hems

exchange. Each type of error produces a characteristic signature in the heat budget that helps explain why many climate models show less cooling than observed.

We are also investigating the problem using ocean-only simulations branched from a state estimate of the ocean, essentially enabling us to examine an ocean model with a density structure similar to observations. Starting our approach from this realistic stratification allows us to test whether stratification alone is sufficient to produce surface cooling when the modeled ocean is adjusted to be in line with real-world estimates of trends in surface heat, freshwater, and wind fluxes.

In this approach, we have found that much of the Southern Ocean's muted warming and large-scale freshening can be explained by climate change forcing alone, even without additional changes in winds or freshwater. However, changes in winds and freshwater then modify this base pattern to produce temperature and salinity trends that more closely resemble observations.

Although this ocean-only approach omits coupled feedbacks, the idealized hierarchical modeling framework removes much of the complexity that shapes more sophisticated climate model responses and enables us to more precisely attribute which portions of the observed pattern arise from specific surface forcings. This allows us to explore questions such as why increased precipitation and increased ice-sheet melt influence the Southern Ocean differently, or whether the poleward shift or strengthening of the winds has played a larger role in driving Southern Ocean temperatures. These experiments reveal not only when realistic stratification is essential to reproduce observed Southern Ocean cooling, but also whether our best estimates of observed forcing affect ocean circulation in the ways inferred from complex models.

Together, our efforts provide a clear explanation for why state-of-the-art climate models struggle in a region that plays an outsized role in Earth's climate and why the Southern Ocean is cooling in the real world. If climate models cannot capture the Southern Ocean's historical behavior, then their projections of future change may be overlooking something important. Identifying the origin of this "missing cooling" is a crucial step toward improving climate models and strengthening our ability to anticipate the planet's future. ▪

"Together, our efforts provide a clear explanation for why state-of-the-art climate models struggle in a region that plays an outsized role in Earth's climate."

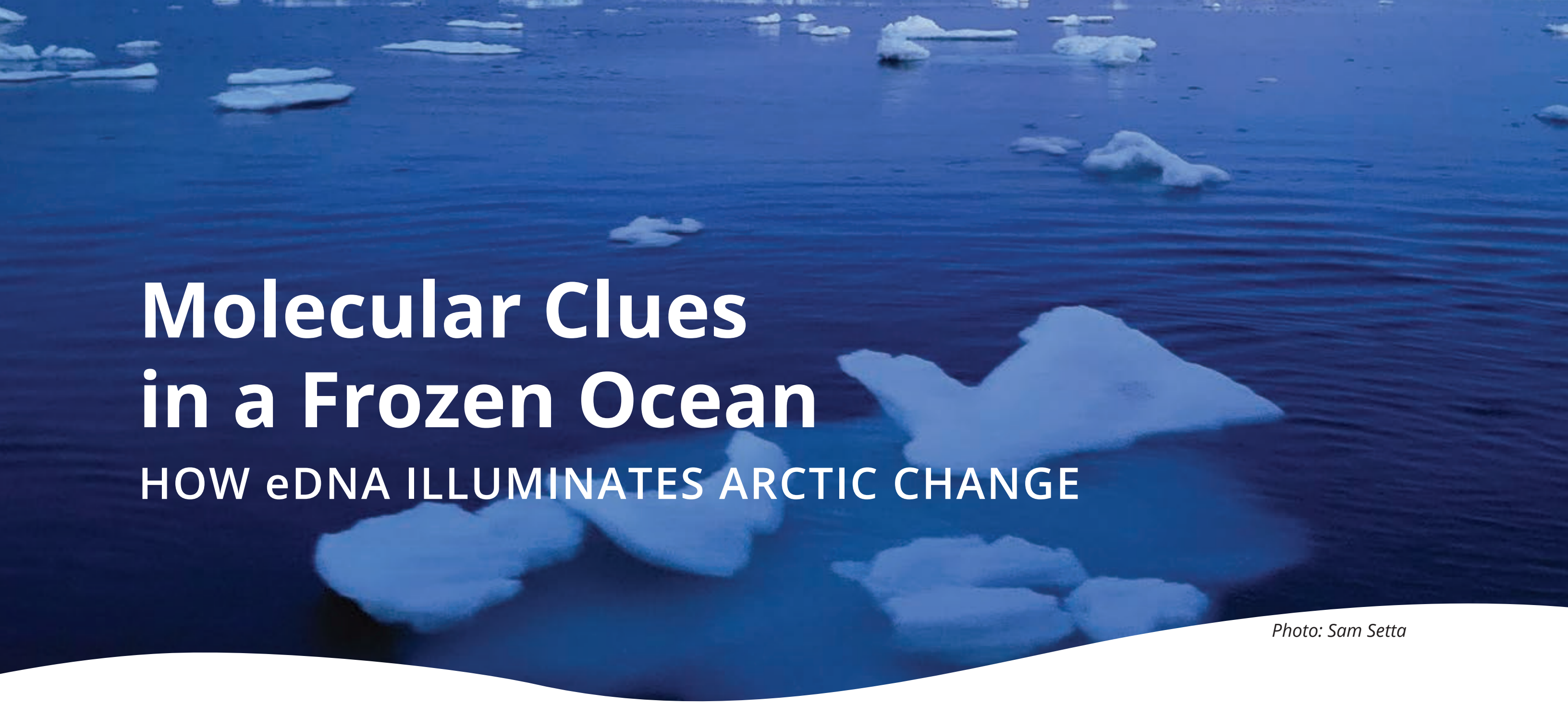

Photo: Sam Setta

View from aboard *Sikuliaq*, a research vessel operated by the University of Alaska Fairbanks

Molecular Clues in a Frozen Ocean

HOW eDNA ILLUMINATES ARCTIC CHANGE

—by Shannon Brown, UW CICOES, with support from Sam Setta, UW CICOES, and collaborators from NOAA Ecosystem & Fisheries-Oceanography Coordinated Investigations

INTRODUCTION

When winter arrives in the Arctic, this region transforms into one of the most extreme and inaccessible environments on Earth. Daylight fades away, temperatures plunge below freezing, and the sea surface in both the Chukchi and northern Bering Seas becomes an expanse of ice. Research here is difficult even in summer, when turbulent seas and sparse infrastructure pose challenges, but once the sea surface freezes, vessel-based fieldwork becomes nearly impossible—limited only to rare transits by icebreakers. Yet beneath the frozen expanse, an entire food web continues to flourish, teeming with microorganisms, phytoplankton, zooplankton, fish, and marine mammals.

So how do scientists study a world they can't access for half the year? How do they detect and monitor the animals living across such an immense and ice-locked region?

CICOES researchers in the Ocean Molecular Ecology (OME) group at NOAA's Pacific Marine Environmental Laboratory are tackling this challenge with a molecular-scale approach. We use environmental DNA (eDNA)—tiny fragments of genetic material shed by organisms—to detect life across the entire tree of life, from bacteria to whales. eDNA acts as a molecular net, revealing which organisms are present and how communities are shifting. When paired with autonomous sampling platforms, eDNA sampling can generate these insights even in regions inaccessible for half the year.

OME uses eDNA to capture species-level and community-level patterns that help fill in information that traditional observing systems are not designed to detect. Rather than replacing traditional approaches such as remote sensing and fisheries surveys, eDNA complements and enhances them—adding a new layer of biological detail to the Arctic research toolbox. This additional resolution enables earlier detection of harmful algal bloom species, and reveals subtle shifts in the food web as sea-ice conditions change.

To study winter dynamics beneath the ice, our group uses autonomous moored water samplers that collect eDNA when most ships cannot access the region. These samplers allow researchers to track how microbial, algal, and zooplankton communities change beneath the ice, and how they respond to environmental shifts. OME also examines the sea ice itself, focusing on ice algae, the microscopic algae that grow inside small water pockets within the ice and along its bottom surface. These algae play an important role in shaping the phytoplankton dynamics below. Together, these efforts contribute an eDNA-based perspective, working in concert with physical, chemical, and biological observations from other researchers, to offer a clearer glimpse into the inner workings of one of the most rapidly changing ecosystems in the ocean.

A MOLECULAR WINDOW ON SEASONAL SHIFTS

Since 2020, our team has partnered with the Ecosystem & Fisheries-Oceanography Coordinated Investigations (EcoFOCI) team to collect more than 1,000 eDNA samples in the Bering and Chukchi Seas. At each site, we use Niskin bottles—special sampling bottles that close at specific depths—to collect seawater. Back on deck, the seawater is processed for nutrients, oxygen, eDNA, and other oceanographic measurements. Some samples are frozen or chemically preserved, while others, like eDNA, are immediately filtered on board.

Our eDNA filtration process is precise and deliberate. We use a specialized pump to push seawater through an ultrafine, enclosed filter, allowing sterile collection and long-term storage for DNA extraction. After filtration, samples are preserved and frozen at sea to await later extraction and processing at PMEL. To capture the full range of life, OME uses five distinct molecular markers that target specific taxonomic groups. As one of the few research groups applying molecular tools at this scale in the US Arctic, our multi-marker approach provides a view of species-level resolution in a region where traditional sampling faces seasonal barriers.

Sequencing from our 2020–2023 collections reveals the remarkable diversity moving through these waters. Fall samples, gathered as sea ice begins to form, and spring samples, collected as sunlight returns and ice retreats, capture the seasonal transitions that shape the Arctic ecosystem. During this sampling window, we detected more than 1,000 species from 39 phyla, including 225 vertebrate species—cod, salmon, lamprey, bowhead whales, walrus, and even Pacific sleeper sharks. The dataset also captured zooplankton that anchor regional food webs, such as copepods, krill, and pteropods, along with ecologically and economically important seafloor species like snow crabs, sea stars, sea cucumbers, and deep-sea corals.

Spring samples also captured the onset of the region's phytoplankton blooms, events that fuel the entire food web. These blooms can be a signal of healthy productivity or a source of harmful algal species that threaten fish, marine mammals, and coastal communities. Tracking their timing and composition provides early insight into how changes at the base of the food web may shape conditions across the region.

TRACKING LIFE BENEATH WINTER ICE

Complementing seasonal ship-based efforts, we deploy autonomous eDNA samplers to collect data year-round, focusing on the winter months when vessels rarely reach these remote ecosystems. Anchored to the seafloor and suspended ~50 m below the surface, these moorings offer a rare glimpse into biodiversity. OME currently uses the McLane Research Laboratories Particle and Phytoplankton Sampler (PPS), a programmable instrument that can filter and preserve up to 24 eDNA samples in a single deployment. We typically deploy these units for a full year and program them to collect samples every two weeks, with more frequent sampling during the spring bloom when biological activity rapidly changes.

Since launching this autonomous program, we have completed five deployments across the Bering and Chukchi Seas. I have personally overseen the careful preparation and deployment of a majority of these units, often in tight shipboard labs or rough conditions. Each unit must be cleaned, primed, and made bubble-free before deployment, when it will be inaccessible for months while sampling eDNA.

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Photo: Shaun Bell

Sam Setta collecting a water sample for eDNA analysis on the 2025 *Sikuliaq* cruise

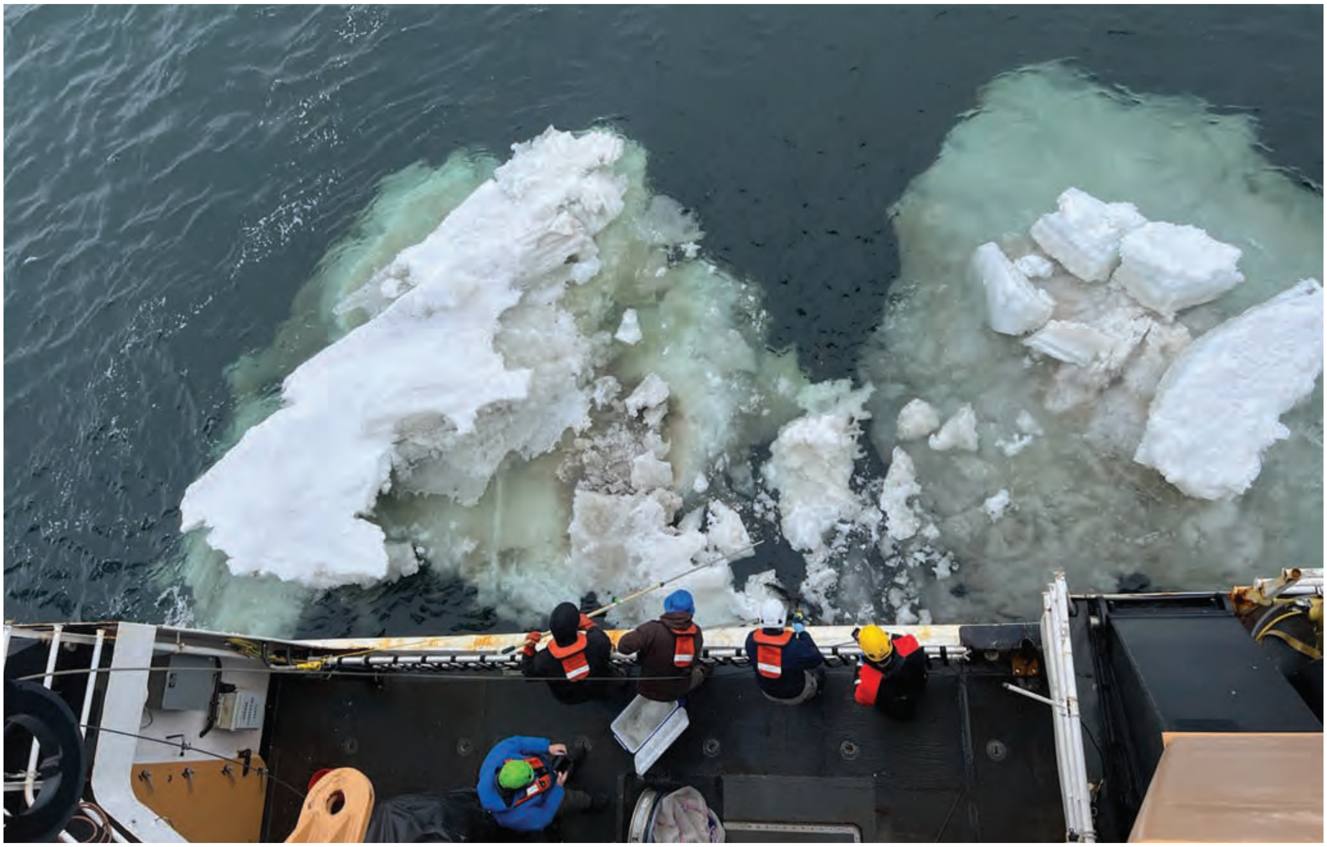

Photo: Carl Rhodes

Crew members gather ice samples.

In fall 2025, two units were deployed in the Bering Sea, programmed to monitor the winter-to-spring transition. By the time the samplers are recovered in fall 2026, they will have captured a continuous record of the Arctic's hidden seasonal rhythms, allowing us to reconstruct entire communities of life, from microscopic bacteria and phytoplankton to zooplankton and fish...all from microscopic traces of DNA.

SAMPLING SEA ICE IN A WARMING ARCTIC

As winter ice melts and spring floes break apart, the ice algae communities living within the ice, often dominated by diatoms, face dramatic changes. Ice algae serve as primary producers at the base of the food web, supporting organisms from tiny invertebrates to marine mammals. Despite their crucial role, these biological communities within the sea ice remain far less studied than their subsurface counterparts in the water column.

When sea ice melts, algal cells are released into the water column, where our autonomous samplers can detect them. But directly sampling the ice itself offers a much clearer picture of the organisms living within it. For decades, Arctic researchers have collected blocks of ice, allowed them to melt slowly, and filtered the meltwater to assess community dynamics. Unfortunately, relatively few sea-ice biological studies have taken place in the US Arctic since 2019, due to reduced ice presence and logistical constraints.

Aboard the NOAA ship *Oscar Dyson* in spring 2025, OME scientist Han Weinrich led our group's first sea-ice sampling effort. When weather and sea conditions allowed the vessel to maneuver close to small, isolated floes, Weinrich worked with the crew to collect ice chunks using a net. Each piece was transferred into sterile containers and left to melt under natural outdoor conditions for up to 30 hours, slow enough to maintain the integrity of the embedded microbial communities. Once fully melted, the water was filtered and preserved for DNA extraction and sequencing. Nine ice-derived samples provide a rare and valuable snapshot of Bering Sea ice-algae communities at the seasonal turning point.

This work is especially timely. The Arctic has experienced unprecedented warming—the ten warmest years on record have all occurred since 2011—making it increasingly important to understand how sea-ice-associated ecosystems are shifting. OME can track species overlap by integrating these ice-derived samples with our autonomous water-column eDNA datasets to understand the interplay between ice-algae and spring phytoplankton blooms in the water column, which play an important role at the base of the Arctic food web.

SHIFTING PHYTOPLANKTON COMMUNITIES

The Arctic is warming nearly four times faster than the global average, reshaping the foundation of its marine ecosystems. OME postdoctoral researcher Sam Setta specializes in using molecular tools to understand how phytoplankton communities respond to shifting ocean conditions. Her work bridges the gap between molecular data and real-world ecological change, helping us determine how the smallest organisms shape the Arctic ecosystems.

As sea ice retreats earlier each year, the timing and composition of phytoplankton blooms change, creating opportunities for new species, including harmful species that can result in harmful algal blooms (HABs), to flourish. One example is *Alexandrium catenella*, a dinoflagellate that forms dormant cysts on the seafloor. These cysts remain inactive until warmer, more stable conditions trigger their transition into toxin-producing cells. Large cyst beds of this species have accumulated in waters in the US Arctic, raising concern that continued warming and changes in ocean circulation could lead to more frequent or widespread HAB events. While there are ongoing monitoring efforts of HAB species, Alaska lacks a robust, well-funded monitoring system comparable to the mainland US West Coast. This makes molecular approaches like Setta's especially valuable, complementing traditional tools.

Using eDNA, OME has detected dozens of HAB-associated taxa, including *A. catenella*, just north of the Bering Strait above known cyst beds, and several toxin-producing *Pseudo-nitzschia* species across the US Arctic. These *Pseudo-nitzschia* species have been observed in the region and produce the potent neurotoxin "domoic acid," known to affect mammals (including humans) who consume it when eating shellfish. "Although these species can cause many harmful impacts to both ecosystems and humans, we still have a long way to go toward understanding how harmful algal blooms will change with shifting ocean conditions," Setta notes. By pairing ship-based eDNA sampling with autonomous sensors that track the spring transition, OME is working to determine where HAB species occur, how they respond to warming waters, and what environmental thresholds trigger bloom formation.

CONCLUSION

eDNA is emerging as an important complement to traditional Arctic observing tools, providing species-level insights into biodiversity, community shifts, and harmful algal blooms throughout the year. By combining ship-based sampling, autonomous samplers, and sea-ice studies, we address three interconnected lines of research: mapping biodiversity and community dynamics, understanding under-ice winter ecosystems, and investigating how ice algal communities influence spring phytoplankton blooms. This integrated, year-round approach provides a high-resolution view of the Arctic, helping scientists anticipate which species may persist or decline, understand how warming waters reshape ecosystem structure, and deliver early warnings of emerging HAB events. Working alongside other research groups, OME is building the predictive tools needed to study, manage, and protect one of the fastest-changing marine ecosystems on Earth. ■

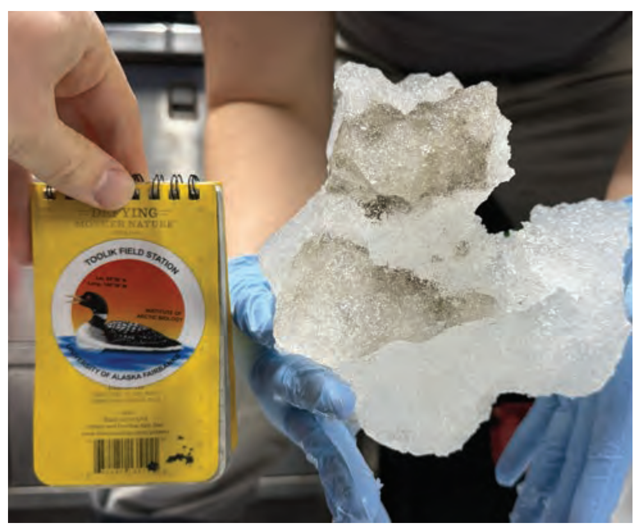

Photo: LTJG J. Robert Logan

Sea ice collected during the 2024 autumn EcoFOCI Mooring Cruise. The brown discoloration on the sample is visible ice algae.

Photo: iStockphoto.com: Dennis Welker

From Cod to Communities

Expanding Climate Risk Research Across Alaska's Fishing Communities

Fishing fleet in an Alaskan harbor

—by Sarah Stone and Lorenzo Ciannelli,
Oregon State University

EASTERN BERING SEA CHANGES

Climate warming is driving major shifts in Alaska's marine ecosystems, including changing the abundance and location of important fish and crab species. These changes are creating new challenges for the people and economies that rely on fisheries. But how do those challenges vary across the many coastal communities in Alaska, and can we anticipate change in ways that might help communities prepare and adapt?

There are few places that illustrate the impact of environmental changes on fisheries as clearly as Alaska's Eastern Bering Sea (EBS). The EBS is one of the most productive marine ecosystems in the world, providing on average more than 40% of the United States' annual seafood catch and supporting some of the largest commercial fisheries globally. However, recent years have brought rapid and dramatic changes to the environmental conditions in the EBS, including rising ocean temperatures and declining sea ice extent. These environmental changes have disrupted the typical life cycle of many species, leading to failures in young fish surviving to adulthood, and triggering mass die-offs in several key fish populations.

Many communities along the western coast of the EBS rely heavily on both commercial and subsistence fishing, as well as on the local fish processing industry. The economic benefits (e.g., profit, employment) and social benefits (e.g., community cohesion, cultural identity, local and Traditional Knowledge) derived from Alaska's fisheries are closely intertwined with the resilience and overall wellbeing of these communities.

As fish and crab move to new areas or fluctuate in abundance, communities must adjust their fishing practices that may have been in place for generations. Adaptation is rarely simple and can be made more difficult due to many types of pre-existing constraints: practical (e.g., size of vessels and gear types); social (e.g., local ecological knowledge and cultural support); and regulatory (e.g., area closures and high cost of permits). While adaptation has always been part of life for coastal communities along the EBS, the current pace and scale of environmental change add new layers of complexity and urgency. Planning ahead has now become more difficult and more important for communities than ever.

Our work integrates climate, ecological, and socioeconomic data to understand how changes in fish populations may affect fishing communities across western Alaska. By identifying which communities face the greatest risk, we can support strategies that build local resilience. Here, we share insights from our initial research focused on Pacific cod, and we outline how our work inspired a larger effort to explore how climate warming is reshaping opportunities and risks for fishing communities across Alaska.

RISK ASSESSMENT FRAMEWORK

To evaluate how climate-driven changes in Pacific cod distributions could translate to risk for coastal communities, we adapted a risk assessment framework developed by the Intergovernmental Panel on Climate Change. In this framework, risk is quantified as the sum of three dimensions: hazard, exposure, and sensitivity.

Hazard

Hazard indicates the extent of predicted change in suitable habitat for Pacific cod. We used species distribution models, four decades of NOAA groundfish survey data, and regional ocean models to predict where Pacific cod are likely to be under different climate scenarios through the end of the century.

To put these predictions into context, we estimated historical distributions of Pacific cod using past environmental data. We did this separately for years with "normal" environmental conditions and years with abnormally warm conditions. Using these different groupings allowed us to evaluate whether projected conditions represent a departure from historical norms, or a continuation of recent extremes.

We then linked changes in the marine habitat to terrestrial Alaska census areas using the spatial overlap between the Alaska Department of Fish and Game's commercial groundfish statistical areas and census area boundaries (see map below). Hazard was quantified as the percent change between the estimated historical distribution and the predicted distribution within each marine statistical area. Census areas where suitable habitat was projected to decline the most were assigned higher hazard scores, while those with stable or increasing levels of suitable habitat received lower hazard scores.

Exposure & Sensitivity

Exposure reflects the degree to which communities are engaged with the EBS Pacific cod fishery. We used data from the National Marine Fisheries Service on the number of fishing permits, vessel ownership, and the total commercial landings by residents of each census area. We also included the number of processing plants within each census area as an additional measure of local fishing infrastructure.

Sensitivity includes dependency (both economic and nutritional) on Pacific cod, and adaptive capacity, or the ability of the community to cope with or adapt to changes in resource accessibility. Sensitivity indicators came from publicly available US Census data and included job diversity, unemployment, per capita income, fuel costs, transportation access, and extent of subsistence use.

For both exposure and sensitivity, we calculated a final value for each census area by summing the relevant indicators and scoring them from 1 (low) to 4 (high).

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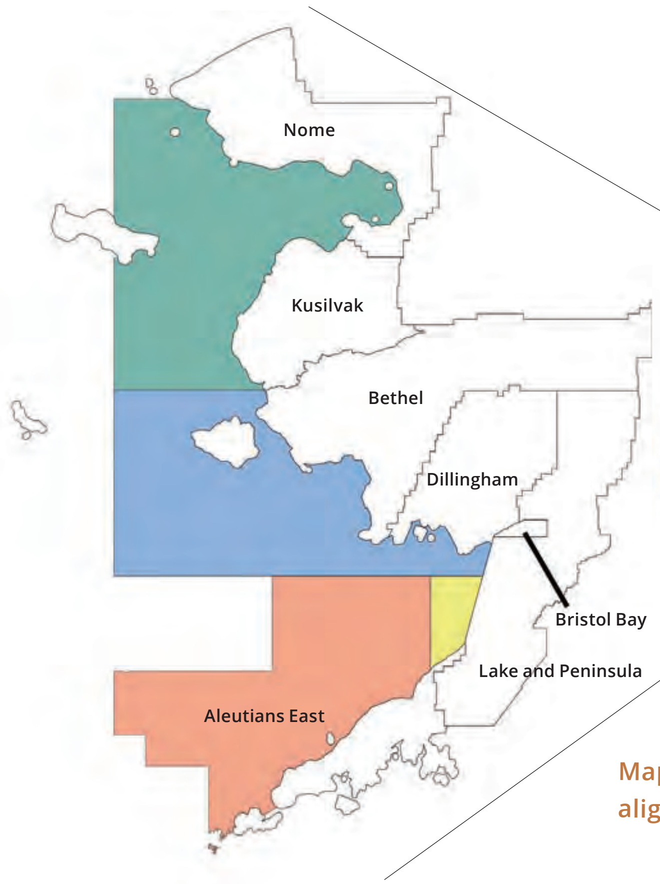
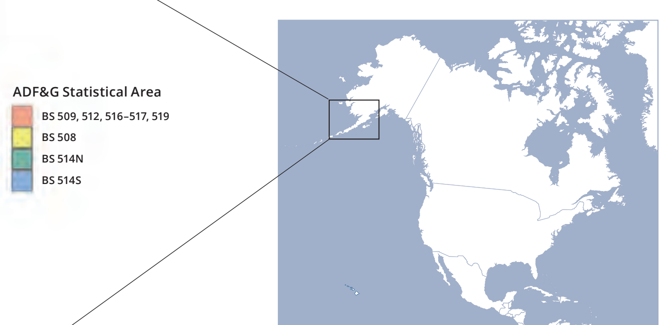




Map of the study census areas and spatially aligned commercial groundfish statistical areas

Overall Risk

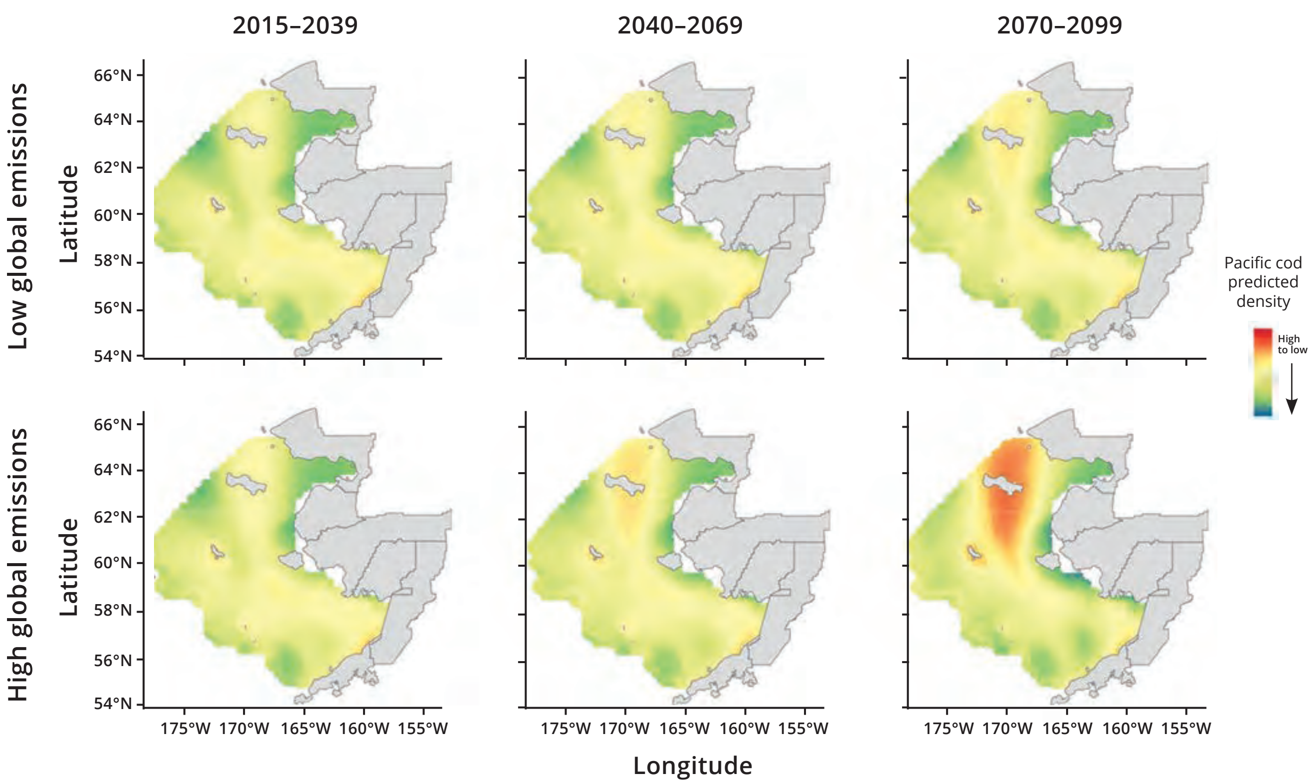
Each census area's total relative risk score was the sum of its scores for hazard, exposure, and sensitivity. Scores were divided into three equal groups that could be classified as relatively low, moderate, or high.

WHAT WE LEARNED

Several key findings emerged from our results. The first was that as the climate warms, suitable Pacific cod habitat is projected to shift steadily northward under multiple climate scenarios (see maps below). By mid-to-late century (2050–2099), these shifts are expected to become substantial and persistent. This movement northward means that suitable summer cod habitat will be located further from communities along the southern EBS, which is where dependence on Pacific cod has historically been the highest. In these places, changes in fish accessibility translate quickly into heightened risk. Southern regions consistently ranked highest across hazard, exposure, and sensitivity; this reflects a strong convergence of ecological change and reliance on cod. The Aleutians East region stood out as a place where declining cod accessibility most strongly intersected with a high reliance on the fishery, thus resulting in higher risk.

Another key finding involved the importance of the capacity for communities to respond to changes in overall risk. The sensitivity indicators we used (job diversity, unemployment, fuel costs, access to transportation, etc.) reflect a community's broader adaptive capacity, or the resources and flexibility that help people adjust when conditions change. When we incorporated this dimension more explicitly into the model, four census areas saw their overall risk level increase. This can seem surprising at first—shouldn't considering adaptability lower risk? But in these communities, limited options for alternative livelihoods and high barriers to change acted like a multiplier for risk rather than a buffer. This result really highlighted the role that social and economic constraints play in determining overall risk for communities.

We do want to emphasize that the framework we describe here should be viewed as a relative measure, rather than a full representation of each community's



Pacific cod relative density predictions, averaged across the remainder of the 21st century and divided into three time periods (columns). The top row assumes a low climate-warming emissions scenario; the bottom row assumes a high climate-warming emissions scenario.

real-world situation. Community resilience and adaptive capacity are dynamic and complex processes that are shaped by history, relationships, and knowledge that cannot be attained from datasets alone. Therefore, understanding the full picture of community risk demands a more in-depth and boots-on-the ground evaluation.

BUILDING ON WHAT WE'VE LEARNED

This initial work provided a basis for understanding how ecological shifts in fisheries translate into socioeconomic risk, while simultaneously revealing opportunities for method refinement and expansion. Building on the Pacific cod study, we are extending this framework to include additional species of groundfish, crab, and salmonids, and we're deepening and refining our analyses. Several major components define the next phase of this work:

1. **Predict catch at fine spatial scales**
   Species distribution models are useful tools for predicting habitat suitability, but they don't necessarily perform well for capturing actualized abundance changes. Similarly, fish distribution does not always directly translate into catch distribution, since catchability depends on vessel characteristics, regulations, and market incentives. To address this, we will model spatial changes in catch and catchability as functions of environmental and regulatory conditions, population-level biomass, and species distribution model projections. This will help bridge the gap between predicted fish distributions and realized harvest patterns that shape community outcomes.
2. **Link predicted catch with port-level landings data**
   Linking modeled catch projections to port-level landings will allow us to evaluate how spatial shifts in fisheries might translate into where the fish are landed, and by extension, which communities may be affected. This step would allow us to estimate how changes in fisheries could alter revenue streams, processing demand, and local employment tied to specific ports.
3. **Identify specific adaptation strategies at a community level**
   Using community-level data, we will simulate different adaptation responses, such as diversifying target species or shifting fishing grounds, to determine which strategies most effectively reduce risk. There are a multitude of factors that go into choosing if, when, and how to respond to changes in fisheries. Because adaptation is shaped by local knowledge, institutions, and lived experiences, this phase includes participatory, semi-structured interviews with community members. Such collaboration between researchers and communities will help ground future risk assessments in local realities and support the development of solutions that are relevant, actionable, and aligned with community priorities.
4. **Evaluate emerging opportunities**
   While our initial work focused on risk of adverse impacts, it's also beneficial to acknowledge that climate-driven changes in fisheries may also create new economic opportunities. Some regions are projected to see positive changes in the abundance of certain species, which could provide an opportunity to engage in new fisheries, revenue streams, and enhance community resilience, especially where these increases in abundance coincide with high adaptive capacity. Expanding our framework to include both risks and opportunities will provide a more balanced understanding of how climate-driven shifts in Alaska's fisheries may reshape resource access for coastal communities.

As we move into the next phase of this work, we are excited to tackle the challenges involved in linking ecological change with social and economic impacts on coastal communities—the story is far from over, and we're just getting started. Stay tuned for what we uncover in the years ahead! ■

The authors would like to thank Sarah Wise and Kirstin Holsman at the Alaska Fisheries Science Center for their contributions to this project and the development of subsequent work.

For more information on the recently completed Pacific cod project, please see the published research paper: Stone S, Wise S, Harte M, Holsman K, & Ciannelli L. (2025). Socioeconomic risk of coastal Alaskan fishing communities to climate-driven changes in Pacific cod distributions. ICES Journal of Marine Science, 82(7), fsaf127. https://doi.org/10.1093/icesjms/fsaf127.

An Autonomous Ballet in the Open Ocean

Photo: NOAA

A Saildrone collecting data

—by Joe Selmont, UW CICOES

On November 22, 2024, two Saildrones rendezvoused with three Wirewalkers and a Seaglider along the equator in the middle of the Pacific Ocean, about 1,700 miles southeast of Hawai‘i. Their meeting set into motion a carefully planned choreography: six autonomous machines moving in coordination as they rode the waves eastward.

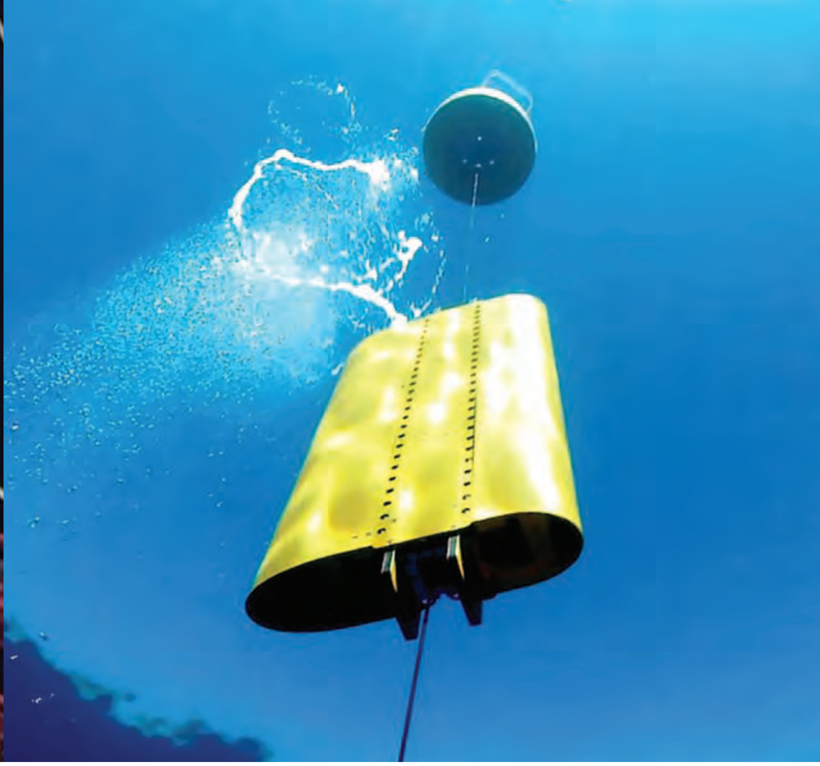
No, this wasn't a scene from a new *Star Wars* movie; Saildrones, Wirewalkers, and Seagliders are three different types of scientific research vehicles known as Uncrewed Surface Vehicles, or USVs. Each of these USVs was collecting data essential to understanding the coupled ocean-atmosphere system.

Deployed as part of Mission 7 of the Tropical Pacific Observing System (TPOS), the Saildrones had already traveled nearly 3,000 miles over the previous two months. They sailed along at roughly two nautical miles per hour, adjusting course in response to occasional commands transmitted by human pilots, who were safe and sound back on dry land. By the time they reached the equatorial rendezvous point, the Saildrones had already gathered a rich set of observations.

> *"Saildrones, Wirewalkers, and Seagliders can roam vast distances with minimal human intervention, transmitting near-real time data back to scientists on shore."*

"These USVs, carrying a whole suite of meteorological, oceanic and biogeochemical sensors, allow us to do adaptive sampling within the TPOS—sometimes surveying shifting frontal regions of a developing system like El Niño, and, sometimes, like here, serendipitously leveraging off of intensive process studies taking place in a key region of the climate system," said Meghan Cronin, an oceanographer with NOAA's Pacific Marine Environmental Laboratory and an affiliate professor at the University of Washington School of Oceanography.

The meeting of the Saildrones, Wirewalkers, and Seaglider marked a rare moment in which multiple autonomous systems—each operating at different depths, speeds, and scales—converged to observe the same dynamic environment. The Saildrones skimmed across the surface, collecting atmospheric and upper-ocean measurements. The Wirewalkers traced continuous vertical profiles, using the power of passing waves to "walk" profilers up and down 2,500 feet of wire beneath the surface. The Seaglider, diving in long, sweeping arcs that reached depths of 3,000 feet, monitored deeper physical and biogeochemical signals.



Photos, left to right: University of Washington, NOAA

left to right: Seaglider and Wirewalker, two types of Uncrewed Surface Vehicles, or USVs

This synchronized survey was designed to capture features of the equatorial Pacific that influence weather patterns across the globe, from droughts in Australia to winter storms in North America. Understanding these processes hinges on both intensive observations and ongoing monitoring. Coordination across three autonomous systems doesn't just triple the amount of data—it provides unique insights that couldn't be obtained by any individual platform.

Historically, intensive field campaigns depended on research cruises and moored buoys. Increasingly, fleets of autonomous platforms like Saildrones, Wirewalkers, and Seagliders can roam vast distances with minimal human intervention, transmitting near-real time data back to scientists on shore.

"Uncrewed vehicles are not only being integrated into observing systems in remote areas of the ocean, such as the tropical Pacific. The USVs are also, for the first time, making it possible to directly measure extreme conditions that are too dangerous for crewed research vessels," said CICOES scientist Dongxiao Zhang. He pointed to a separate effort as an example: the research team is using USVs to observe air-sea interactions inside hurricanes—work that could transform understanding of rapid intensification and ultimately lead to better hurricane forecasts.

The weeklong collaboration with the Wirewalkers and Seaglider represented only one part of the broader TPOS mission. Over their months-long journey, the Saildrones provided both high-resolution measurements and broad spatial coverage of key air–sea interactions in the tropical Pacific. With the hope that missions like this can be conducted frequently enough to study patterns and variations in the data, the TPOS research team is building a future in which autonomous observing systems work together in a choreographed scientific ballet, one capable of revealing the processes that shape Earth's climate. ■

The TPOS USV missions started in 2017 and more information can be found here: https://www.pmel.noaa.gov/ocs/tpos-usv.

The Wirewalkers were deployed from the R/V Sikuliaq *during the NSF-funded MOTIVE (Mixing belOw Tropical Instability waVEs) cruise, led by Chief Scientist Caitlin Whalen of the University of Washington Applied Physics Laboratory.*

The Seaglider was deployed by CICOES and UW School of Oceanography graduate student Katie Kohlman from the same R/V Sikuliaq *cruise.*

The USV Hurricane Observation missions started in 2021; more information can be found here: https://www.pmel.noaa.gov/usv-hurricane/

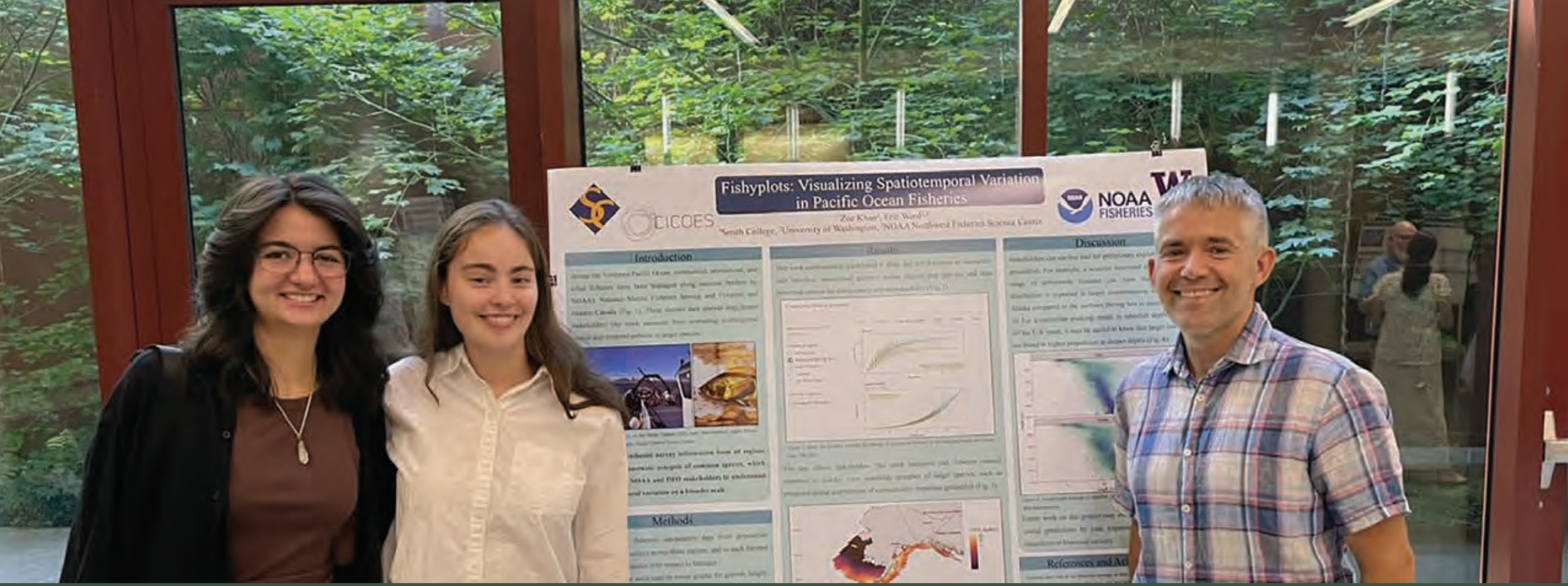


Photo: Courtesy of Zoe Khan

A Summer of *Fishyplots*

A New Tool for Making Cross-border Fisheries Data Accessible and Easy to Understand

—by Zoe Khan and Callie Murakami

Callie Murakami (left), Zoe Khan (middle), and their mentor Eric Ward (right) showcase their research at the CICOES Intern Symposium in August 2025.

Do you like fish? And statistics? Read on!

Government agencies like NOAA in the US and Canada's Department of Fisheries and Oceans (DFO) conduct surveys to assess the status of marine ecosystems. These surveys often focus on fish populations that are protected or commercially important, and results of this work are used to inform policy decisions, such as providing information about how many fish can be caught by fisheries each year.

On the west coast of the USA and Canada, from California to the Bering Sea, there are 14 different trawl surveys to monitor groundfish species. Fish populations mix across international and state borders, making it important to combine datasets across regions to understand how populations are changing. Differences across regions may include growth rates, size, or total biomass. While these surveys are publicly available and their methodology is similar, their nuances have made it a challenge to combine them.

> *"Fish populations in this region mix across international and state borders, making it important to combine datasets across regions to understand how populations are changing."*

And that is where we come in! Thanks to 2025 summer internships funded by the University of Washington CICOES and Varanasi programs, we were able to help address these concerns. We've built a tool to join data across borders, making the data collected by NOAA and DFO accessible, reproducible, and transparent to stakeholders. With a few clicks, anyone will be able to investigate trends across regions, and policymakers like fisheries council members can use this as a tool to quickly summarize population trends, informing fisheries management.

OUR EXPERIENCE

Coming into this project, our coding experiences were limited to what we had learned about the R programming language in class and during some outside research. R is used for statistics and data visualization, which is exactly what our project called for. More specifically, we needed to learn how to develop an R "package"—a specialized set of custom functions for our fisheries survey data. We would also need to code not as individuals, but as a team. Luckily, as quick learners with an incredible team of support, it didn't take long to set us up for success. We jumped straight into the world of GitHub, a tool for collaborative coding. Our first few days may have felt a bit like skydiving, but we were not without a parachute.

Our principal mentor, Eric Ward, walked us through the inner workings of package development and taught us how to implement functions, write documentation, and update shared code. He also coached us on the nuts and bolts of GitHub, which began to feel less like a byzantine contraption and more like an essential resource. Thus, the R package fishyplots was born.

Days in the office soon settled into a productive flow. We began working on the specific functionality of our package, determining which plots would be most desirable for our end users. Our original inspiration for visualizations came from a previous report by DFO's Sean Anderson and previous visualizations by NOAA's Chantel Wetzel and Matt Callahan.

Each plot was its own particular challenge. Some needed specific data, alternate formats, adaptable text, and lots of tinkering and testing. As an illustration, one of our plots is a map of predicted fish-catch density from the most recent survey year. To make this map, we needed to wrangle data, fit a spatial model to observations, make predictions from that model, and finally make the visualization. Most of these steps were new to us, but we picked up some great skills along the way, including spatiotemporal modeling.

OUR LARGER TEAM

Every week, we met a larger team from across all the science offices to discuss the intricacies of our plots, work through changes, and plan next steps. The team has worked extensively with this data, including the data collection process, so they knew valuable background information and the inner workings that are vital for how we interpret and display our results. For example, one suggestion from the team was splitting the Alaska data into two separate subregions spanning the Gulf of Alaska and the Bering Sea to better demonstrate differences in survey methods and fish biology between these areas. It required some backtracking and reformatting of the data on our part, but made a big difference later on when we were able to see variations in the fishes and the trends between these two areas that we would not have noticed otherwise. Along the way, the team always gave tips and suggestions to help us get to know the data better and understand how context can make all the difference.

Alas. There were days when we wanted to throw our poor laptops out of the window. An example of one of these times was when we accidentally ran a coding

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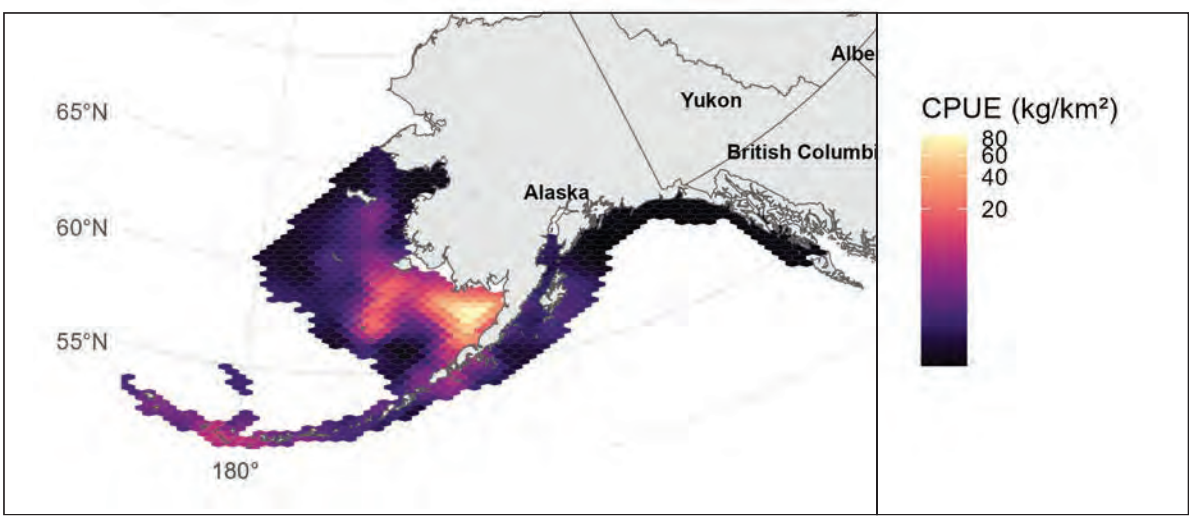

Predicted density for Northern rock sole in four survey subregions. Color scale is fourth-root transformed. Survey year: Gulf of Alaska (2023), northern Bering Sea (2023), eastern Bering Sea (2024), Aleutian Islands (2024).

program that would end up taking five hours to complete (oops!), or when the same error message popped up about a thousand times before we found the bug in the script.

The learning curve was definitely steep, but our mentors supported us through it all. For example, Kelli Johnson taught us advanced GitHub techniques using command lines. Imagine a programmer in a movie hacking into a heavily secured computer system—that's a bit what this felt like (except less stressful). Megsie Siple, our knight in shining armor, was instrumental in helping us with the R package Shiny, which is a way to write an interactive app. This package is what we used to construct our website interface and function. Since we were both new to making websites, her guidance was invaluable.

A RESPECTABLE R PACKAGE

By August, fishyplots had grown into a respectable R package, and we, into respectable scientific software developers. The first time we got the Shiny app up and running was very gratifying. The website is aptly named Pacific Survey Explorer, and towards the end of the summer, we presented it to many groups at both the Northwest and Alaska Fisheries Science Centers. Since most of the time we had been a bit secluded in the office, it was very exciting to see so much investment in the project! We received a lot of positive and constructive feedback, which will be used to make improvements to the app in the future. For example, we hope to add to our list of species and expand the website to include data from other types of surveys.

Going forward, there are countless opportunities for continued research now that we have this rich source of combined regional data. We had a great time this summer working towards this goal and can't wait to see the future applications of our work. ▪

About the authors

Zoe Khan is a junior studying Statistics and Geobiology at Smith College. Her 2025 summer internship was completed through the CICOES Intern Program, which is funded by the National Science Foundation, the National Oceanic and Atmospheric Association (NOAA), and the University of Washington (UW).

Callie Murakami is a senior at the UW, studying Aquatic and Fishery Sciences. She was funded by the 2025 Varanasi Internship through the UW and NOAA, endowed by Usha and S. Rao Varanasi.

To check out fishyplots, scan the QR code

Photo: iStockphoto.com: Laura Ragsdale

Fishing boat with nets deployed

Tungsten Inert Gas Welding Class

—by Matias Gradilla and Jason Broad,
UW CICOES

We took a Tungsten Inert Gas (TIG) welding class held at the Hazard Factory, a functional welding shop that doubles as an educational setting with a focus on different welding units such as wire fed MIG, Flux, stick, and TIG machines. The purpose of the Hazard Factory is to show people how to operate different models of welders and also help welders with any difficulties.

By taking this week-long class, we gained more of a grasp on TIG welding and also performed better welding techniques on aluminum; aluminum is a metal that is not easy to weld because it is prone to overheating, which causes blowouts. It was difficult, but it was also satisfying to be able to successfully weld the material.

Taking this class not only brought in new experiences for us but also brought value to our workplace. Due to not having much welding experience on TIG, our shop was sending projects to get welded outside of our lab, which is not cost effective. Being able to weld our projects in-house will bring down project costs for our lab. ▪

Matias Gradilla and Jason Broad learned how to weld with Tungsten Inert Gas at the Hazard Factory.

Photos: Courtesy of Matias Gradilla and Jason Broad

INTERN EXPERIENCE IN
Nome, Alaska

Photo: Courtesy of Anjali Shah

Anjali Shah on a hike in Nome, Alaska

In 2024, Anjali Shah (Brown '25) spent 9 weeks at the NOAA Pacific Marine Environmental Laboratory (PMEL) as a NOAA Hollings Scholar working with the EcoFOCI program. She conducted an initial exploration to quantify the spatial and temporal extent of ice associated with open water phytoplankton blooms from an operational field test of a glider deployed in the Bering Sea in 2023. To further her experience, she traveled to present at the University of Alaska Fairbanks Strait Science lecture series in Nome, Alaska, in August 2024.

—by Anjali Shah, Brown '25, NOAA Hollings Scholar

ARRIVING IN NOME

After 17 hours of flying, 5 different time zones, 3 chocolate croissants, 2 macarons, 2 cups of coffee, and 3 seasons of Derry Girls, I breathed a sigh of relief after our tumultuous landing. The winds stung my face as we walked from our plane to the airport terminal, where we sought a cab in the area. Thus began my experience in Nome, Alaska, on the doorstep of the US Arctic and just around the corner from the Bering Strait.

> *" Less sea ice fosters different species of phytoplankton during blooms, which means slimmer pickings for commercial and recreational hunters and fishers all over Alaska. "*

About 500 miles from two of the state's largest cities, Anchorage and Fairbanks, Nome is only accessible by sea or air. The town center is exposed to the Bering Sea's winds and waves, necessitating the elevation of many buildings a foot above ground level to avoid flooding. The community's roughly 3,700 residents practice subsistence and recreational hunting and fishing, especially since barged-in goods are highly priced. Many Alaska Native community members hunt seals, walruses, and other marine mammals.

The availability of these resources depends on yearly sea ice advance and retreat. Each spring, this cycle stimulates phytoplankton blooms that drive productive fisheries. However, amplified warming at higher latitudes has decreased yearly sea-ice cover. Less sea ice fosters different species of phytoplankton during blooms, which means slimmer pickings for commercial and recreational hunters and fishers all over Alaska.

STUDYING ARCTIC CLIMATE

So how do we study such a complex, rapidly changing system? Climate models are one answer, but models need observations to validate them, and—to put it bluntly—Arctic observational oceanography is hard. NOAA, CICOES, and other research institutions use a variety of methods and instruments to collect data, such as moored buoys and research cruises, but the hazards of sea ice, storms, and complex currents can upend missions or destroy oceanographic instruments. The sheer volume of ice also limits where we can put instruments in the water. However, it is impossible to understand how fisheries and sea ice are changing near cities like Nome without high resolution data collection. So, how do we solve this problem?

Part of the answer may lie in the Oculus seaglider, developed by University of Washington Applied Physics Laboratory and NOAA's PMEL over the past decade. This instrument continuously feeds water through temperature, salinity, chlorophyll, oxygen, light, and turbidity sensors in order to characterize both the physical and biological aspects of the surrounding marine environment. Additionally, this instrument can move up and down in the water column without human assistance, which has created a newfound wave of "autonomous" oceanographic observations that require much less physical effort than collecting data manually.

The glider also collects higher resolution data than conventional moorings and floats, allowing scientists to observe how the smallest-scale variations in the physical ocean environment (temperature, salinity, and light) impact biological patterns like chlorophyll and oxygen. For example, extremely cold temperatures in one location may be associated with high chlorophyll and oxygen concentrations, indicating high biological productivity. However, high salinities in a new location may correlate to diminished chlorophyll and oxygen levels, indicating sensitivity of the biology in the region to small-scale physical conditions.

The glider's first deployment in 2017 successfully allowed oceanographers to identify how small-scale rotating eddies can be hotspots of biological activity, with implications for fisheries off the coast of northwest Alaska. In 2023, the glider traveled within 5 kilometers of the ice-edge off the coast of southwest Alaska, capturing the physical and biological influence of ice melt in the ocean and creating the basis for my summer research. In 2022, the glider traveled to Bering Strait waters off of Nome. A local family worked with NOAA PMEL crew members to deploy the Oculus glider aboard their boat the *Audrey Kadi*, helping to spearhead the first successful glider journey through the narrow and stormy Bering Strait. This risky experience (of almost losing the glider itself) represents a meaningful aspect of the Oculus mission: conducting science with communities. Collaborating with communities like Nome helps build relationships with local people so that we, as scientists, can shape our research around community needs.

PRESENTING MY RESEARCH

This brings us back to my arrival in Nome in August 2024. My mentor, Heather Tabisola, was set to give a talk at the Strait Science lecture series, organized by Alaska Sea Grant agent Gay Sheffield. She made sure I had the opportunity to join her and present my summer research with the Oculus mission. The citizens of

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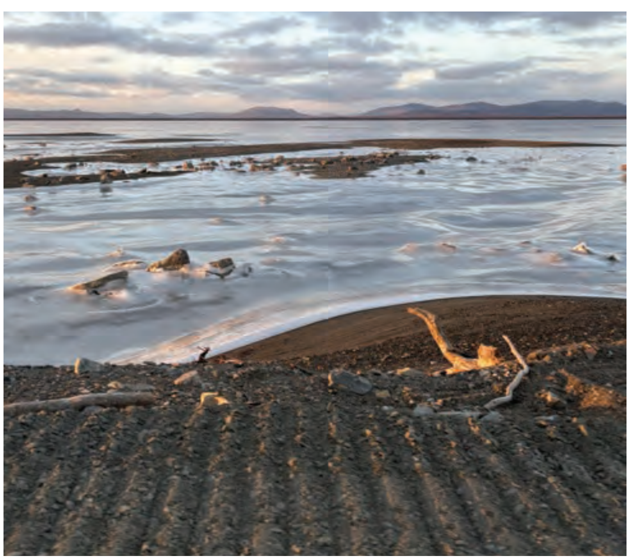

Photo: Anjali Shah

Photo: Courtesy of Anjali Shah

above: Welcome to Nome, August 22, 2024
left: River ice near Safety Sound, October 24, 2025

Photo: Anjali Shah

A muskox near Dexter, Alaska, October 24, 2025

Nome have been predicting biological hotspots (large fish populations) based on physical conditions (storms, ice, wind, and ocean currents) since time immemorial, so presenting at Strait Science allowed us to discuss findings rather than share one-sidedly, creating an open forum of conversation between communities and scientists. The goal of such interactions is to listen to what communities need and what research will help them in the future, as well as listen to new perspectives on our data.

The morning before the talk, Heather and I were headed to have breakfast at a bakery, where we discovered no open seats. A fisherman and his friend beckoned us to come sit with them and we proceeded to chat for over two hours. He told us about how the king crab fishing had never been better, and that he noticed the impact of ice on the microscopic algae of the area, which eventually fed the crabs and helped his business. This story shocked me, since this was exactly what my talk would discuss! I perked up immediately as he brought it up, and I told him I had noticed similar patterns in my data, and used a machine learning algorithm to bring them to light. He was impressed with the methods, but unsurprised by the results.

During our talk, I discussed how the glider traveled through distinct oceanographic regimes, one with low temperature and salinity conditions, which reflected the influence of ice. This prompted a fisherman to comment on the fact that he often observes herring near such ice-influenced fronts. The project's principal investigator, Phyllis Stabeno, was surprised by this insight and asked the man for more details on the placement of the herring: were they above or below the salinity front? Closer or further from the ice? It was a prime example of open-flow communication between oceanographers and fishermen in order to advance collective knowledge: it helped us as scientists think about new questions for future research to back up the fisherman's observations.

AFTER GRADUATION

After graduation, I started a position at the University at Alaska Fairbanks at the Alaska Center for Climate Assessment and Preparedness (ACCAP). I work to document the local impacts of extreme weather events on communities, from storms to wildfires to harmful algal blooms. Through this role, I once again had the opportunity to present in Nome in October 2025, this time about coastal flooding. I integrated information from scientific articles, storm damage reports, and *The Nome Nugget*, the local newspaper, to create a full picture of the impacts of fall storms and coastal flooding in the area. We also hosted open office hours, where people provided valuable anecdotes about their own storm experiences. We recorded some of these conversations and created audio clips about storm impacts for the ACCAP website.

All forms of climate science are inherently linked to natural resources, public health, and infrastructure needs. Through my experience working with CICOES and NOAA, I rediscovered why I do science in the first place: for people, especially coastal communities vulnerable to the impacts of climate change. Wherever my career takes me, I can only hope that this remains an integral aspect of my work. ■

View the presentations

RETIREE PROFILE
Kevin O'Brien

Photo: Courtesy of Kevin O'Brien

—by Carol Pérez, with support from Joe Selmont

We celebrate the remarkable career of Kevin O'Brien, who retired after nearly 35 years of service at CICOES. Before embarking on his scientific journey, Kevin worked in Alaska at a salmon cannery, which speaks to his strong work ethic and sense of adventure. From there, he pursued his passion for science, earning opportunities that eventually led him to the University of San Diego and, later, to the University of Washington.

Over the years, Kevin became an integral part of CICOES and NOAA's Pacific Marine Environmental Laboratory, where he contributed to the Data Integration Group and played a key role in advancing ocean observation systems. As Vice-Chair for Data and Information for the Global Ocean Observing System (GOOS) Observations Coordination Group (OCG), Kevin helped shape global strategies for ocean data sharing and integration, leaving a lasting impact on the scientific community worldwide.

His career represents not only scientific excellence but also a deep commitment to teamwork and innovation. As we honor his career, we extend our heartfelt gratitude and warmest wishes for the next step in Kevin's journey.

Our interview with Kevin has been lightly edited for length and clarity.

Q: Over your 30+ years with UW, what major changes have you seen in marine science, especially where it overlaps with your expertise in data science?

A: The idea of free and open data, and the introduction of the FAIR data principles, were two major shifts in the data landscape. Historically, PIs were quite protective of the data they collected in order to prevent themselves from being "scooped." But, as people realized these data were collected using public money and that the data could be valuable for other efforts, there was increased pressure to make data freely available at a more rapid pace. I would guess that the fears of being "scooped" were also not really warranted. I also think we are on the brink of discovering how AI can improve (hopefully) data management and workflows.

Another innovation was the introduction of autonomous platforms to observe the ocean. This has led to data opportunities and challenges that we are still working on today, as there has been a massive increase of in situ data volumes. This is due not only to the increased frequency of observations, but also the sheer number of sensors on these platforms.

Q: Do you have any standout memories or projects from your time at UW?

A: Through the support of NOAA Global Ocean Monitoring and Observing (GOMO), I was fortunate to find myself as part of an international effort to improve data flows of the global in situ networks. This work was done through GOOS and the OCG. In fact, I was the first GOOS vice-chair for data when I was selected as the OCG Vice-chair for Data and Information almost a decade ago. Through this work, I was able to develop an OCG Cross-Network Data Implementation Strategy, which is being implemented now, and also be part of the team that developed the data strategy for the UN Ocean Decade. Working on this effort has allowed me to positively impact the data efficiency of the global in situ networks.

Another highlight was the development of the Open Access to GTS project, which made it easier for

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> “Working with the SOCAT community has been incredibly rewarding, as it’s one of the first projects I’ve been involved in that both data managers and scientists came together to develop a data system that was useful for both.”

anyone to access and exchange data with the World Meteorological Organization’s (WMO) Global Telecommunications System (GTS). The GTS is how data is exchanged in near-real time to support operational activities such as forecasting and safety of life at sea. However, the GTS is a closed system, and extremely difficult to navigate. The Open-GTS project highlighted ways to improve this process, and illustrated where the choke points were. Since this project, the WMO has launched their WIS 2, which shares many of the same principles that I piloted with the Open-GTS project. The project was selected as an endorsed activity of the UN Ocean Decade, and will continue after I leave CICOES.

Lastly, I’d be remiss if I didn’t mention SOCAT, the Surface Ocean CO_2 Atlas. Through the last decade, we’ve integrated a data submission system that has allowed SOCAT to be annually released, and provide a combination of submission and quality control tools for scientists and technicians. SOCAT is the data product that is the heart of the newly emerging Surface Ocean Carbon Reference Network (SOCONET). Working with the SOCAT community has been incredibly rewarding, as it’s one of the first projects I’ve been involved in that both data managers and scientists came together to develop a data system that was useful for both. I cannot overstate how important this was to the success of SOCAT and the idea of a SOCONET.

Q: You’ve accepted a new position in Europe. (Very cool!) What will you be working on there, and what excites you most about it? More broadly, where do you see the field of marine science heading in the years ahead?

A: I will be the Technical Coordinator for the Surface Ocean Carbon Reference Network (SOCONET), which is an emerging global in situ network of the GOOS. I will be working to ensure that SOCONET is integrated into the GOOS and the GOOS monitoring center, OceanOPS. Technically, I will be an international civil servant working through the WMO, but I will be located at the OceanOPS headquarters at IFREMER, the French institute for ocean science in Brest, France.

As for marine science in the future, I can’t really say, but I do know it will be data-heavy and it will continue to be incredibly important to implement data flows based upon known standards and conventions. Machine-to-machine data exchanges will be the norm, and more and more data will start coming in from nontraditional sources. There is a lot of work to do, but we have to ensure that data adheres to the standards that can make all of this happen efficiently and effectively. ■

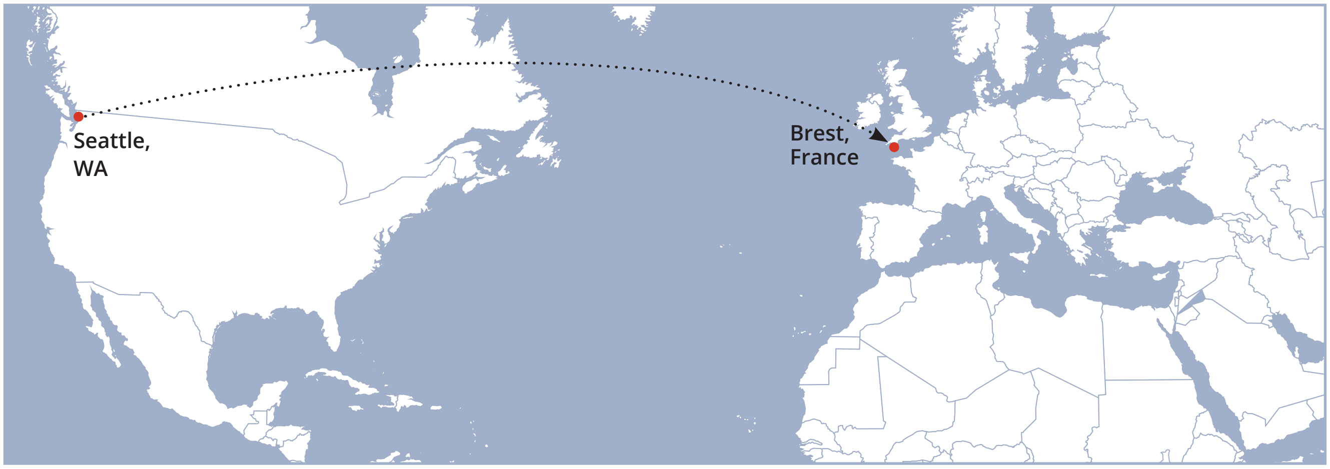

Illustration: iStockphoto.com: loops7

Kevin O’Brien relocated from Seattle, Washington, to Brest, France to serve as the technical coordinator for the Surface Ocean Carbon Reference Network.

DETECTING DUNGENESS

Tracking Crab Populations Through Environmental DNA

Photo: iStockphoto.com: Durk Talsma

Dungeness crab on a pier

—by Han Weinrich and Shannon Brown, UW CICOES, with support from Sean McAllister, UW CICOES, and Dwan Jackson, NOAA Experiential Research and Training Opportunities

Dungeness crab (*Metacarcinus magister*) are the focus of one of the West Coast's most lucrative fisheries, generating over $200 million annually. Beyond its monetary value, this keystone species plays a critical role in the coastal food web, both as a predator of clams, worms, and small crustaceans and as a vital food source for fish, sea otters, and other marine mammals. Dungeness crab abundance helps maintain balance across benthic communities along the US West Coast. And for generations, tribal communities have relied on Dungeness crab for sustenance, observing traditional catch periods and sharing critical knowledge that continues to guide species management today.

Understanding how these crabs grow, survive, and respond to changing ocean conditions is key to protecting both the species and the fisheries that depend on them. The life of a Dungeness crab begins far from the seafloor. Newly hatched larvae are tiny, transparent drifters, carried by currents, feeding and molting through several planktonic stages before reaching the "megalopa" phase. Megalopa, which are less than half an inch long, begin their slow migration towards nearshore habitats where they settle into the sediment and grow into adult crabs. Environmental conditions, such as temperature, salinity, and ocean acidification, have a major impact on this species, especially during their larval stages. Acidified waters interfere with shell formation and molting, making the larvae more vulnerable to predators and reducing the number of young crabs that reach adulthood.

Monitoring these early life stages is critical for understanding both population trends and ecosystem health. Traditional survey gear designed for adult crabs can't catch larvae, so scientists rely on specialized nets and traps to collect the pelagic larval stages. Once collected, megalopa must be counted by hand—an extremely labor-intensive process, considering that a single trap can yield tens of thousands of individuals. To expand on current monitoring efforts, scientists are turning to molecular tools to detect the crabs' presence through traces of free-floating DNA.

In collaboration with the Swinomish Indian Tribal Community, the Pacific Northwest Crab Research Group, and a NOAA Coastal and Marine Ecosystems Scholar, CICOES researchers in the PMEL Ocean Molecular Ecology (OME) group are developing a quantitative Polymerase Chain Reaction (qPCR) assay capable of detecting Dungeness crab in water samples. This assay has the potential to support and supplement trap data with quantitative population estimates.

BRINGING MOLECULAR TOOLS TO CRAB MONITORING

The single-species qPCR assay, designed by OME, uses environmental DNA—the DNA naturally shed by organisms into their environment—to detect

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Dungeness crab. In general terms, an "assay" is a standardized analytic method used to detect, measure, or evaluate a specific substance, process, or activity. Blood tests to measure cholesterol levels, breathalyzers to measure alcohol levels, and swimming pool test kits to measure chlorine levels—these are all common examples of assays. In our context, our qPCR assay uses a molecular approach to estimate the amount of Dungeness crab DNA within a given volume of seawater. By collecting seawater and amplifying the DNA it contains, we can confirm whether Dungeness crabs are present. And crucially, we can also estimate their relative abundance in a given area.

Our qPCR approach allows for a faster, less labor-intensive way to estimate crab abundance, which can improve our population assessments by allowing us to add temporal resolution and environmental diversity in our observing network. In environments where directly sampling and counting organisms is difficult, collecting eDNA for qPCR analysis only requires a water sample. In cases where organisms are difficult to identify visually, qPCR can use their genetic signature to verify their identity—reducing the burden on scientists. When organisms are too small, too rare, or even too plentiful to count efficiently by hand, qPCR uses molecular amplification to mathematically determine how much DNA is in a sample, which can then be used to estimate abundance in the environment.

PRIMERS AND PROBES

Designing a qPCR assay is easier said than done. The process started with DNA sequencing. To build an assay that can accurately detect Dungeness crabs, we first extracted DNA from individuals collected across the species' full range, capturing natural genetic variation among populations in the design. Then, to ensure the assay wouldn't detect the wrong species and give a false positive, we also obtained sequences of closely related species. Once all sequences were in-hand, we combed through thousands of DNA base pairs to find a single gene region unique to Dungeness crab.

After locating the right target, we designed the molecular tools required to make a qPCR work: primers and probes. These tiny, custom-built DNA fragments are designed to bind precisely to the target gene and fluoresce when detected. New tools and robust workflows streamline this design to ensure the assay chemistry functions reliably and that the primers and probes are bound only to Dungeness crab DNA under standard qPCR conditions.

Photo: Sean McAllister

Dwan Jackson, NOAA Coastal and Marine Ecosystems Scholar, collects seawater directly from a light trap to be filtered for eDNA.

CRAB MIX-UPS AND A CLEVER FIX

After this groundwork was complete, we tested the assay in the lab on synthetic DNA that mimics the crab gene we were targeting. A successful result signified a working assay, at least under ideal laboratory conditions. Unfortunately, nature is rarely so cooperative. The next validation steps included running the assay on tissue collected directly from Dungeness crab and other closely related species.

It was during this stage that our team ran into an unexpected problem: the king crab and red rock crab samples were also testing positive for Dungeness crab. At first, we suspected a flaw in the assay design, but after retracing every step of the process, the culprit turned out to be contamination—just not in the lab. The tissue sample had come from Seattle's famous Pike Place Market, where different crab species sit side-by-side on shared ice, creating an environment perfect for cross-contamination!

The solution? A world-first crab-cleaning technique. Before extracting new tissue samples, we wiped the crabs down with a mild, DNA-destroying bleach solution. Once retested, the false positives disappeared. Our assay wasn't wrong; it was so sensitive that it could pick up the faint genetic signature of the neighboring Dungeness crab.

FROM LAB TO OCEAN: FIELD VALIDATION

Once we confirmed our assay was both sensitive and specific to the Dungeness crab, we coordinated with the Pacific Northwest Crab Research Group (PNWCRG) to begin real-world testing. Through PNWCRG, we collaborated with Sarah Grossman, an environmental specialist with the Swinomish Indian Tribal Community, to sample the Tribe's light traps suspended on docks throughout Anacortes, Washington. A light trap is an active sampler that depends on the larvae's attraction towards a light

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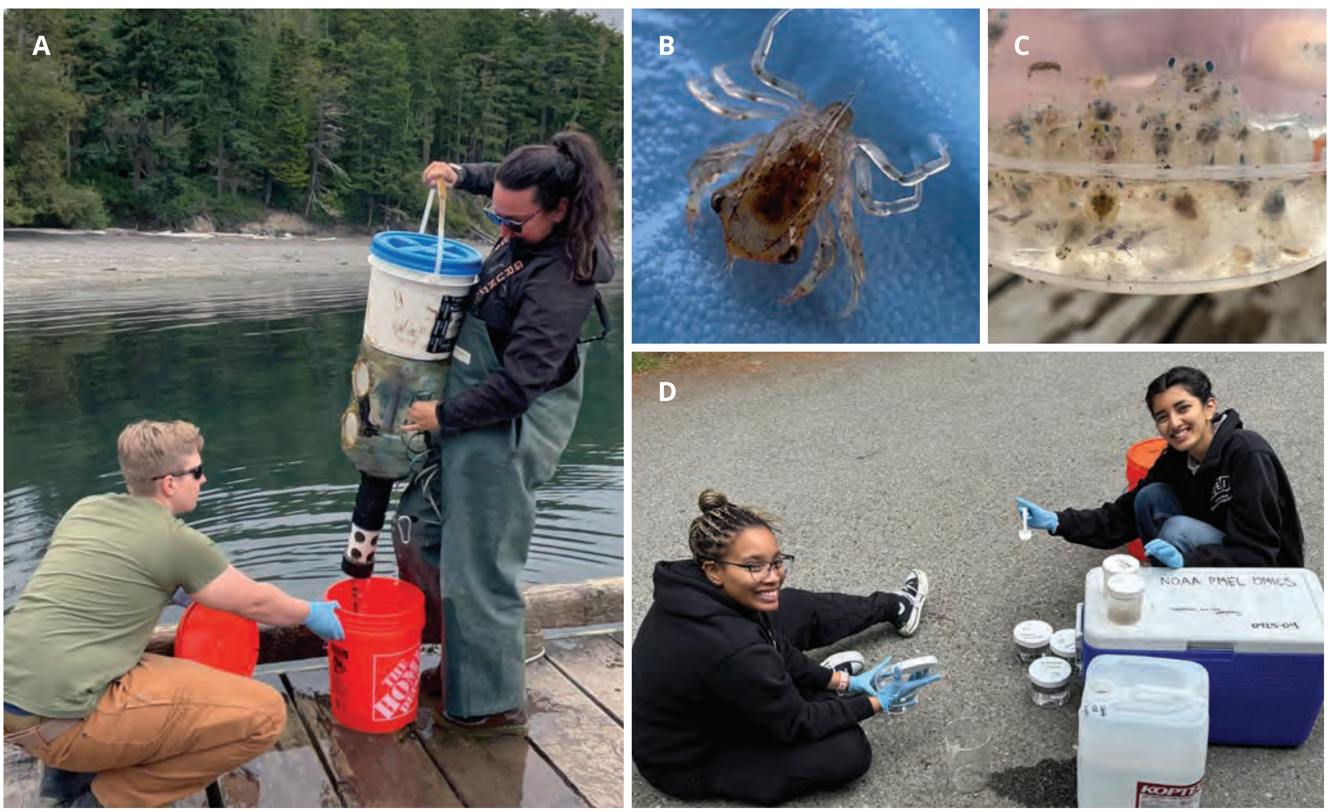

Photos: A: Mugdha Chiplunkar, B–D: Han Weinrich

A) Han Weinrich collecting sea water from the Swinomish Indian Tribal community light trap to be filtered for eDNA; B) Close-up image of a Dungeness crab in the megalopa larval stage; C) Dungeness crab megalopae, the final larval stage before settling to the seafloor, collected from a light trap prior to DNA analysis; D) OME students Dwan Jackson and Mugdha Chiplunkar sorting crab larvae.

source, funneling them into a collection chamber where escape is nearly impossible. Sarah and her colleagues at Swinomish have led juvenile crab research using light traps for many years, and have collaborated on this work with tribal and non-profit partners throughout the Salish Sea.

We collected megalopae from the light traps at several sites and then tested whether manual counts of larvae matched eDNA-based detections. To do this, we added increasing numbers of megalopae to jars filled with preservative. The preservative was then removed from each jar, filtered, and extracted for DNA. These samples were run through our assay, allowing us to see how the strength of the eDNA signal changed with the number of larvae present. To complement these tests, we also collected seawater samples directly from the light trap water.

After running our assay on the crab jars, we found a clear pattern: the amount of detected crab DNA increased with increasing numbers of crab megalopae in the jar—good news for the quantitative power of the assay. Water samples collected from inside the light traps also contained crab DNA, demonstrating that the assay could successfully detect Dungeness crab in real-world environmental samples with unknown population sizes.

Despite these promising results, our experiments indicated that detections were only consistent at higher densities. In the context of Dungeness crab recruitment, where successful cohorts number in the tens to hundreds of thousands, these thresholds still fall within a biologically meaningful range. This suggests that the assay has utility for tracking population abundances, but is less suited for identifying low densities as seen in open water eDNA samples. Future work will need to explore how DNA shedding rates vary across life stages, and evaluate whether methodological refinement improves sensitivity at the lowest abundance levels.

SCALING UP: TOWARD COMPREHENSIVE MONITORING

Seeing the strong correlation between our manual counts and the DNA concentrations from our qPCR assay gives us confidence that we're capturing larval abundances accurately and reliably. We can use qPCR to assess Dungeness crab numbers not just from preserved plankton samples, but directly from light-trap water, which opens the door to scaling up monitoring across broader regions and longer timeframes.

Expanding this approach along Washington's coasts should give us earlier insight into seasonal trends and help us understand how stressors like ocean acidification and marine heatwaves are affecting these vulnerable young crabs. By combining sensitivity, efficiency, and scalability, this novel assay strengthens our ability to forecast population trends, and supports sustainable management as the ocean continues to change. ■

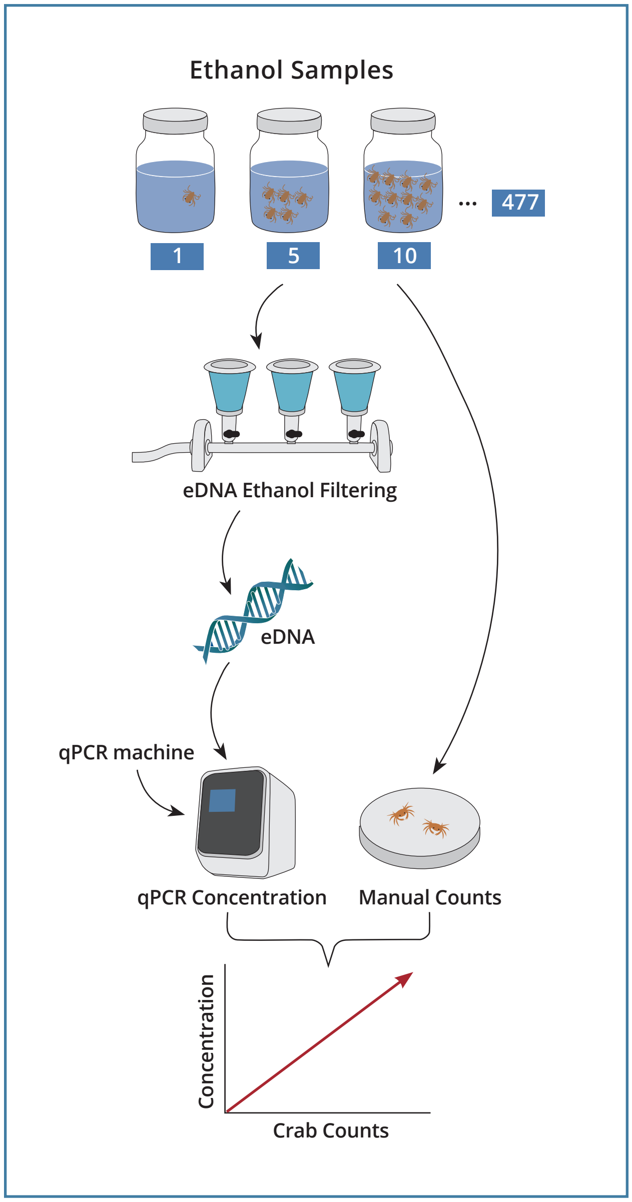

illustration: Dwan Jackson

Experimental design for determining the relationship between crab counts and concentration

FUNDING AND INITIATIVES

Photo: iStockphoto.com: Brian Logan

Ruby Beach at Olympic National Park, Washington

The Cooperative Institute for Climate, Ocean and Ecosystem Studies (CICOES) was originally established as the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) in 1977 to foster collaborative research between the National Oceanic and Atmospheric Administration (NOAA) and the University of Washington (UW). In 2020, this collaboration expanded to include academic partners at the University of Alaska Fairbanks (UAF) and the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University (OSU). The Institute name changed to reflect the broadening mission and partnership. Among the oldest of NOAA's nationwide system of Cooperative Institutes, CICOES is at the forefront of important and impactful investigations on climate, ocean, and ecosystem science.

CICOES scientists work internationally with academic scientists, research institutions, government agencies, NGOs, and local community organizations. Through collaborative efforts, CICOES researchers and affiliates strengthen and extend their areas of expertise in the service of regional, national, and global community interests.

RESEARCH

CICOES and NOAA researchers represent a broad range of expertise within nine core themes:

- Climate and Ocean Variability, Change, and Impacts
- Earth Systems and Processes
- Environmental Chemistry and Ocean Carbon
- Marine Ecosystems: Observation, Analysis, and Forecasts
- Ocean and Coastal Observations
- Environmental Data Science
- Aquaculture Science
- Human Dimensions in Marine Systems
- Polar Studies

Investigators focus on critical issues, including:

- Collecting and analyzing data to better understand physical, biological, and chemical processes of ocean and coastal areas
- Increasing our knowledge of climate variability, change, and impacts on ecosystems
- Studying hydrothermal vents and volcanoes on the seafloor
- Studying effects of interactions between human communities and natural ecosystems
- Developing tools and technologies to study, restore, and protect marine habitats
- Improving tsunami forecasting and prediction of impacts
- And much more; visit the CICOES website for further details: cicoes.uw.edu/research/

—continued on page 52

> *"Among the oldest of NOAA's nationwide system of cooperative institutes, CICOES is at the forefront of important and impactful investigations on climate, ocean, and ecosystem science."*

FUNDING

CICOES research and administration is funded through five tasks:

TASK I is the Institute's "core" program. It contributes to the administration of CICOES and is the principal funder of most of our internal Initiatives, including the:

- Postdoctoral scholar program
- Graduate student fellowships
- Research development grants
- Visiting scientist program
- Summer internship program (funded mostly by NSF)

TASK II provides funding for research scientists, postdoctoral scholars, and technical staff who work at the local NOAA laboratories in directed, collaborative research efforts between NOAA and university scientists.

TASK III supports research related to CICOES' themes on the UW, OSU, and UAF campuses, and includes a broad range of departments. Principal Investigators include university academic and research faculty, as well as research scientists.

TASK IV represents externally funded projects, including all sponsored research funding that is not part of the NOAA Cooperative Agreement (e.g., grants from the National Science Foundation or the North Pacific Research Board). The total Task IV funds for 2025 were $4,463,920.

TASK V includes NOAA funding under two federal initiatives: the Inflation Reduction Act and the Bipartisan Infrastructure Law. In 2025, CICOES was awarded $2,918,962 in Task V funds, the majority of which went to partner departments at UW and UAF.

INITIATIVES $274,710 TOTAL

Funded by Task I, NSF, and internal UW sources, CICOES supports several initiatives.

Summer Internship Program $157,210

Since 2008, CICOES has welcomed undergraduate students from across the United States and US territories to participate in a nine-week summer internship that opens doors to hands-on research and scientific discovery. Each intern works closely with a mentor—an experienced scientist at the University of Washington or one of our federal partners—to design, carry out, and share the results of a research project. Leveraging funds from the NSF, the program supported 14 interns in 2025.

Postdoctoral Scholars Program $0

Since 1977, CICOES has committed a significant share of its initiative budget to annually support up to three 2-year postdoctoral research scholars. Postdocs are provided the opportunity to conduct their own research project, think broadly, and work with the distinguished scientists at UW, UAF, OSU, and the NOAA laboratories. Due to budget uncertainty and constraints, the program was temporarily suspended in 2025, and has resumed as of 2026.

Graduate Student Fellowships $47,500

Since 2019, CICOES has awarded up to six student quarters per year to support graduate work conducted in association with CICOES and NOAA research scientists as well as UW faculty in CICOES-affiliated departments.

Research Development Grants $0

Since 2015, CICOES has allocated an average of $120,000 per year to stimulate new, innovative research. Due to funding uncertainty and constraints, the program was temporarily suspended in 2025, and has resumed as of 2026.

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CICOES FUNDING TO OTHER UW DEPARTMENTS

Applied Physics Lab	$355,420
Atmospheric & Climate Sciences	$238,353
EarthLab	$145,870
Oceanography	$2,911,742
Aquatic & Fishery Sciences	$1,176,894

$18,118,531
TOTAL COOPERATIVE AGREEMENT FUNDING*

BY CONSORTIUM PARTNERS

UW	$16,485,199
UAF	$1,633,331
OSU	$0

BY TASK

Task I:	$479,940
Task II:	$11,925,294
Task III:	$5,713,297

BY THEME

Climate and Ocean Variability, Change and Impacts	$2,380,280
Earth Systems and Processes	$1,565,451
Environmental Chemistry and Ocean Carbon	$2,351,244
Environmental Data Science	$1,057,000
Marine Ecosystems: Observation, Analysis, and Forecasts	$3,994,885
Ocean and Coastal Observations	$5,384,251
Polar Studies	$339,720
Multiple	$1,045,699

** Does not include Task IV and Task V funding, which are outside the scope of the Cooperative Agreement.*

Photo: iStockphoto.com: Brian Logan

Professional Development Program $25,000

Since 2019, CICOES has allocated $25,000 per year for employees to use toward professional development opportunities. See examples featured on pages 13 and 41.

Employee Engagement $20,000

CICOES is committed to building and fostering a workplace and scientific community where all contributions are valued and respected. The range of perspectives available to us directly affects our ability to innovate and push the boundaries of our research. $20,000 of internal UW funds per year are allocated to support this work.

Visiting Scientist Program $25,000

The Visiting Scientist Program promotes scientific exchanges that strengthen existing collaborations, promote new collaborations, and/or offer opportunities for educating staff on new ideas. Visitors interact with CICOES scientists as well as with scientists in other units of the UW College of the Environment and/or NOAA research facilities, and they present at least one public seminar on their research interests. The initiative is allocated up to $25,000 per year. ▪

Map: iStockphoto.com: loops7

Communicating Science to Journalists; Delivering Information to the Public

Photo: iStockphoto.com: Eloi Omella

Aerial view of Humpback whales (*Megaptera novaeangliae*)

—by Norm Mah, UW CICOES

The work of CICOES and NOAA scientists advances understanding of how the global ocean interacts with the Earth's atmosphere, ecosystems, and climate systems, providing vital data that supports improved weather and climate predictions, sustainable fisheries management, and enhanced coastal community resilience.

Our scientists engage the public by communicating their subject matter through interviews with journalists. These ongoing communication opportunities increase understanding of natural and anthropogenic impacts on ecosystem health and socio-economic sustainability. CICOES and NOAA research enables better forecasts, earlier warnings for natural disasters, and a greater understanding of the Earth.

Public attention to our work often spikes following major environmental events, such as tsunamis or extreme and destructive weather. During these times, journalists rely on CICOES and NOAA experts to explain complex science in accessible terms. This media engagement helps the public understand:

- How our research protects lives and property
- The coordinated efforts between scientists, engineers, and operational teams
- The importance of continued investment in monitoring and prediction systems

Recent examples include, but are not limited to:

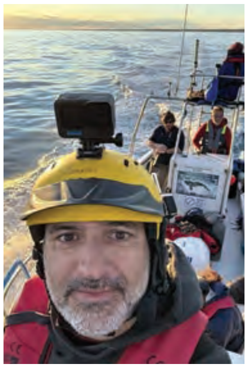

Photo: Alex Zerbini

Alex Zerbini

Alex Zerbini, CICOES senior research scientist and leading expert on the development and application of satellite telemetry technology for large cetaceans. He is quoted in a recent *National Geographic* article about orcas ramming boats. Alex participated in a workshop that made several recommendations to the International Whaling Commission.

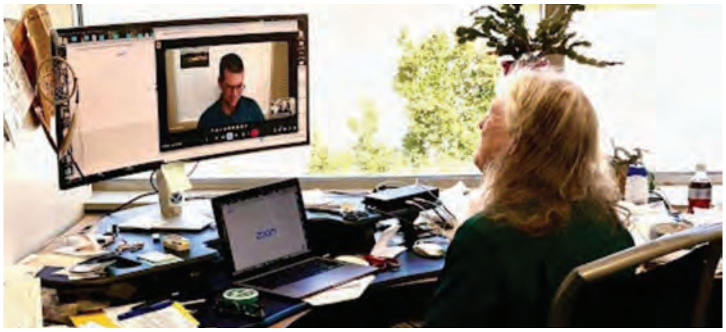

Photo:Norm Mah

Phyllis Stebeno

Phyllis Stebeno, Principal Investigator of NOAA's EcoFOCI program, was interviewed by Science.org about Bering Sea warming (2018–2019) and its link to declines in snow crab populations. The warmer waters in the Bering Sea caused snow crabs to crash. Scientists are working to predict the future of the fishery.

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Photo: Courtesy of Wali Rana

left to right: Sean Cheng, Anuscheh Nawaz, Aircraft Commander Sarah Cozart, and Jiaxu Zhang.

Jiaxu Zhang, CICOES and NOAA/PMEL physical oceanography research scientist focuses specifically on Arctic freshwater content and its distribution. She was interviewed by KNOM radio, Nome, Alaska, about the 2025 September Arctic Air Field Survey. She's led a team of researchers to Nome for the Arctic Airborne Investigations and Research project, or Arctic AIR for short.

The Arctic AIR team logged 41 flight hours with NOAA's Twin Otter over the Northern Bering, Chukchi, and Beaufort Seas. The campaign produced 13.5 hours of high-quality and 2 hours of intermediate-quality hyperspectral imagery for ocean color, and all eight planned microSWIFT-TS buoys were deployed, six of which are reporting data. The team also conducted bowhead whale reconnaissance in the Beaufort and observed belugas in the Northern Bering Sea.

Vasily Titov and Yong Wei are part of a team of researchers in the NOAA Center for Tsunami Research (NCTR) and work in partnership with Tsunami Warning Centers and the National Weather Service National Data Buoy Center to improve tsunami warnings and preparedness by enhancing measurement technology, optimizing monitoring networks, improving the accuracy of forecast models, and improving the prediction of coastal impacts.

Vasily and Yong were featured in multiple news outlets (NBC News, *The New York Times*, CNN, KOMO News, KATU News) following the Kamchatka tsunami in July 2025. ■

For a digital version of this story with links to CICOES, NOAA PMEL, and the news stories featured, scan the QR Code below.

Photo: Norm Mah

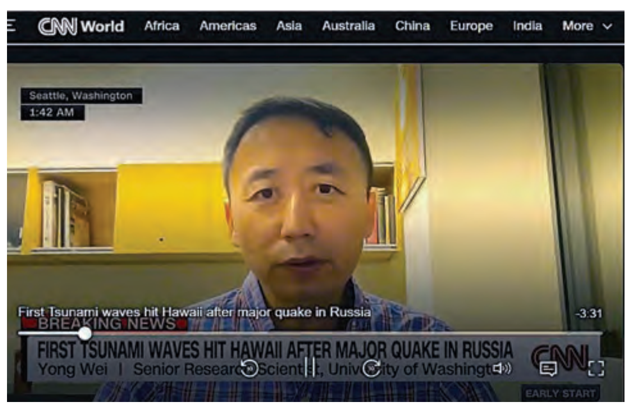

Photo: Screenshot—CNN interview

top to bottom: Vasily Titov being interviewed by KOMO TV; Yong Wei being interviewed on CNN following Kamchatka tsunami in July 2025

GET TO KNOW
Our New Employees

Photo: Anjali Shah

Sunset in Nome, Alaska

Please welcome these 14 individuals who joined the CICOES-UW staff between December 2024 and November 2025.

Hanna Best is a member of the Atmospheric Chemistry group at NOAA PMEL. She works on the development, testing, and operation of novel sea-going aerosol instrumentation systems, with a specific focus on designing autonomous sampling systems for the extended collection of atmospheric data over the ocean. Prior to joining CICOES, she graduated with a BS in Environmental Engineering from the University of California, Davis. During her time at UC Davis, she worked as a student researcher at the Air Quality Research Center and interned with NASA.

Dave Bonan is a CICOES Postdoctoral Research Fellow in the Department of Atmospheric and Climate Science. He is working with David Battisti (UW) and Wei Cheng (NOAA PMEL) to investigate how climate model resolution impacts key physical processes in the climate system, such as long-term trends in sea-surface temperatures. The research is aimed at explaining the discrepancy between observed and modeled Southern Ocean cooling over the past few decades. He is also researching the physics of extreme events, such as heatwaves over the land and ocean surfaces. Prior to joining CICOES, he received his PhD in Environmental Science and Engineering from the California Institute of Technology.

Garrett Feroy is a Data Consultant for the Carbon group at NOAA PMEL. He earned his Bachelor's of Earth Science from CEOAS at Oregon State University, where he majored in Oceanography and minored in Geology. Before joining CICOES, Garrett worked as a Lab Assistant at the O.H. Hinsdale Wave Research Laboratory, as a Hydraulic Selector Valve Assembly Technician, and volunteered at the MaST Center Aquarium as an Aquarium Technician, member of the Plankton Project, and Nudibranch Research Team. He spends his off days fishing, hiking, or listening to classic rock music.

Kee Onn Fong is a postdoctoral researcher at PMEL focusing on the exchange of gases between the ocean and atmosphere. He earned his PhD in Aerospace Engineering and Mechanics in 2021 from the University of Minnesota. At PMEL, he works with the Engineering Development Division and the Carbon Group to develop a new instrument for measuring carbon parameters in seawater on autonomous platforms. Previously, he also worked as a postdoc on air-sea gas exchange in the Labrador Sea at UW APL, and on spray formation in Mechanical Engineering at UW. He has been a Seattle resident for four years and enjoys cycling with the Cascade Bicycle Club in his free time.

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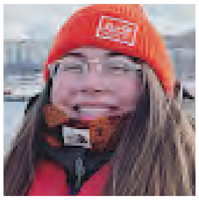

Caroline Fradette is a research scientist with the PMEL Carbon Group and holds an MSc in Oceanography from Dalhousie University in Halifax, Nova Scotia. Her professional focus is on ensuring the highest quality of carbon system measurements, both in the lab and at sea, with a keen interest in improving standard operating procedures, particularly in challenging coastal and estuarine environments. When she's not immersed in carbon chemistry, Caroline can be found reading, playing video games and Dungeons & Dragons, visiting local breweries, and enjoying time with her dogs.

Jasen Jacobsen is a Postdoc with a dual appointment at CICOES and Oregon State University. Before joining CICOES, he was a postdoctoral scholar at Oregon State University, where he used numerical models to investigate physical and ecological drivers of zooplankton variability along the Oregon and Washington shelf. He holds a Bachelor's, Master's, and PhD in Oceanography from Humboldt State University, North Carolina State University, and the University of California, Santa Cruz, respectively. His research broadly focuses on how physical oceanographic processes shape marine ecosystems. Outside of work, he enjoys spending time outdoors with his family and his dog, Rossby, and can often be found hiking, fly fishing, cross-country skiing, or surfing.

CICOES currently has 120+ employees.

Our current longest-serving employee has been here for 35 years!

Austin Lightfoot is an Engineering Development Electronics Technician at NOAA PMEL. He provides technical support to both the Engineering Development Division and PMEL as a whole. Prior to joining CICOES, Austin worked as a product designer and engineer in the musical equipment industry.

Matt Luongo is a CICOES Postdoctoral Research Fellow who studies large-scale climate dynamics through the lens of physical oceanography and coupled ocean-atmosphere interactions. Before joining CICOES, he earned his PhD in Oceanography at Scripps Institution of Oceanography, UC San Diego in 2024 and a joint BA in Earth & Planetary Science and Environmental Engineering at Harvard in 2017. Matt's postdoctoral work at UW focuses on understanding drivers of observed ocean temperature and salinity trends over recent decades. Matt uses model hierarchies and observational analyses to understand how historical climate change has dynamically affected the Equatorial Pacific and Southern Ocean, two regions with outsized influence on global climate.

Sarah Nickford is a postdoctoral scholar who earned her PhD in Oceanography at the University of Rhode Island Graduate School of Oceanography in 2023. Sarah works with Adrienne Sutton and Evan Howard to investigate high frequency variability of surface ocean pCO_2 and its drivers. Her work uses uncrewed surface vehicles to collect data at the air-sea interface, targeting remote regions and harsh weather conditions where observations are historically undersampled. The overarching goal is to advance the application of these new and emerging technologies, leading to wider adoption of new observing assets in the global ocean observing system to address gaps in observing and knowledge of surface ocean carbon variability and change.

Darren Pilcher is a research scientist, rejoining CICOES and NOAA PMEL following his previous position at the NOAA Northwest Fisheries Science Center. Darren completed his PhD in Atmospheric and Oceanic Science at the University of Wisconsin where he worked on freshwater and marine carbon cycling. At CICOES, he works with the PMEL Carbon Group to develop modeling tools and products tracking and predicting ocean acidification in support of fisheries. He also studies the effects of changing environmental conditions on marine ecosystems through the Changing Ecosystems and Fisheries Initiative (CEFI) and develops model simulations to test marine carbon dioxide removal techniques. He enjoys baseball, football, and reading science fiction and history.

Kazumi Schubert is a research scientist/engineer in the Marine Carbon Group at PMEL. She graduated and earned her MS at Hokkaido University in Japan, then started her career as part of the team that launched and got the seismic survey operation up and running in JAMSTEC. She is involved in many different types of ocean observations and loves working in the field. Then she moved to WHOI to work as a marine technician of R/V Atlantis and Submersible Alvin. She is interested in biogeochemical oceanography and excited to join the Carbon team.

Joe Selmont is the Education, Outreach, and Communications Specialist for CICOES. He holds a BA and an MPA from the University of Alaska Anchorage, where he spent six years as the College of Engineering's Director of K–12 Outreach before moving to Seattle. At CICOES, Joe leads the undergraduate internship program, produces the institute's annual magazine, and supports a wide range of education, outreach, and communications projects. He is passionate about sharing stories of scientific discovery and wonder. Outside of work, Joe writes poetry and explores the outdoors.

Photo: iStockphoto.com: Nancy Pauwels

Booth Island, Antarctica

Lindsey Transue is a Research Scientist with CICOES, currently working with NOAA's Alaska Fisheries Science Center to advance passive acoustic monitoring projects. Building on her previous work conducting baleen whale distribution studies at NOAA's Northeast Fisheries Science Center, she focuses on research that directly supports the conservation of protected species. Lindsey holds a BS in Ecology and Evolutionary Biology from the University of Tennessee and an MS in Marine Biology from the College of Charleston.

Sophia Wagner is a marine mammal bioacoustics analyst in the Passive Acoustics Group at NOAA's Alaska Fisheries Center. Prior to joining CICOES, Sophia earned her bachelor's degree in biology and environmental studies at Haverford College. In the lab, Sophia spends her time identifying marine mammal species by sound. This informs many projects, which range from using acoustics to better understand the population and range of the endangered eastern subpopulation of North Pacific right whales to training machine learning to detect ringed-seal "double knocks." She also assists on research cruises deploying and retrieving hydrophones in the Bering Sea. Sophia enjoys the rewarding challenge of deciphering rich ocean soundscapes.

Publications

Photo: Shannon Brown

CICOES researchers authored or co-authored the following publications between November 2024 and October 2025.

A field of ice floes in the Bering Sea, as seen from the deck of the NOAA *Oscar Dyson*

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Photo: Erin Fedewa

Red king crab

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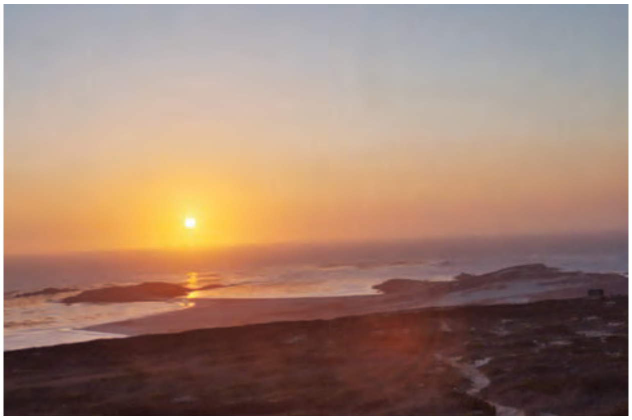

Photo: NOAA Alaska Fisheries Science Center

Sunset over San Miguel Island

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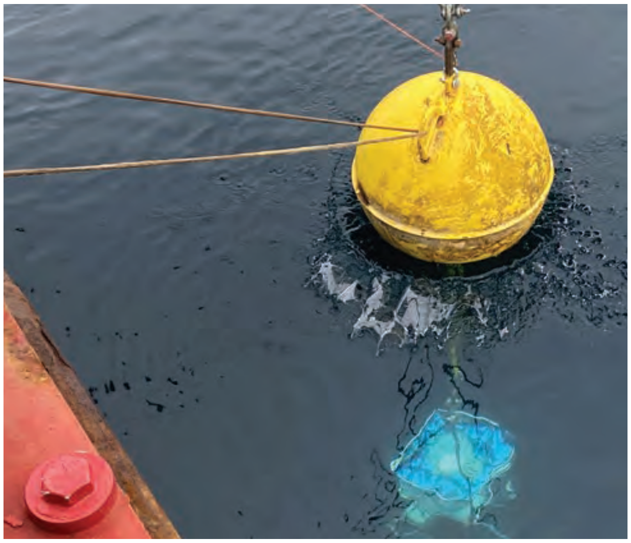

Photo: LTJG J. Robert Logan

Deploying eDNA technology off the *Sikuliaq*

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Crew members aboard NOAA's *Oscar Dyson* prep sampling equipment for deployment.

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NOAA ship *Oscar Dyson*

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Another colorful sunset on San Miguel Island

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