COOPERATIVE INSTITUTE FOR CLIMATE, OCEAN, AND ECOSYSTEM STUDIES

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Cooperative Institute for
CLIMATE, OCEAN & ECOSYSTEM STUDIES

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ON THE COVER
Scientists surveying and sampling icebergs temporarily trapped in the landfast sea ice near Utqiagvik, Alaska.
Photo: Ignatius Rigor
Story on page 4

From the Director

Photo: College of the Environment

John Horne

The proposal to create CICOES was submitted on January 3, 2019. That seems like a long time ago and at the same time, very short as we worked to establish the co-located consortium that we proposed. Don't get me wrong, there has been a tremendous amount of infrastructure created and great science accomplished among the three partner universities in the first five years of CICOES. The renewal proposal for the second 5-year cycle should be nearing completion or submitted by the time you read this.

The transition from JISAO to CICOES represents much of the collaborative research community among government and academic institutions in the Pacific Northwest. The inclination of left coast scientists to seek north-south connections was formalized among the University of Washington, the University of Alaska Fairbanks, and the College of Earth, Ocean and Atmospheric Sciences at Oregon State University. Since its inception, CICOES has maintained longstanding government–academic programs among our three primary NOAA partners—the Pacific Marine Environmental Laboratory, the Alaska Fisheries Science Center, and the Northwest Fisheries Science Center—and is building new partnerships with other NOAA agencies, including the National Weather Service and the National Environmental Satellite, Data, and Information Service. Our research portfolio is wide in breadth and equally deep in expertise.

> *"A constant in the CICOES' first five years is change that accompanies growth…Whenever we seem to be feeling confident about our policies and procedures, government and/or academic norms shift and we adapt to those changes."*

A constant in the CICOES' first five years is change that accompanies growth. Our research efforts evolve with changes in NOAA's strategic research objectives, emerging issues, with the ebb and flow of funding opportunities, and through common interests among scientists. Economic cycles and institutional administrative changes in financial systems have required staff at all three consortium partners to adapt (and there has been a fair amount of frustration and angst involved). Whenever we seem to be feeling confident about our policies and procedures, government and/or academic norms shift and we adapt to those changes. We're all still adapting to the UW's adoption of the Workday financial system and the Federal Government's switch to eraCommons.

In the last year, there have been three significant events: the CICOES renewal review, new federal funding initiatives, and a federal election. During the fourth year of a Cooperative Agreement, each Cooperative Institute must undergo scientific and administrative reviews by external

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Photo: Wirestock at iStockphoto.com

From the Director

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and NOAA panels. The scientific output, policy, and procedures are examined to determine if the Cooperative Institute is meeting its scientific, education, and outreach goals. I'm happy to report that CICOES received a grade of outstanding in its scientific and administrative reviews. I want to thank all those who contributed to the preparation and participated in the reviews. It was a very full three days. We have received the panel reports and are now reviewing the recommendations to make CICOES even better.

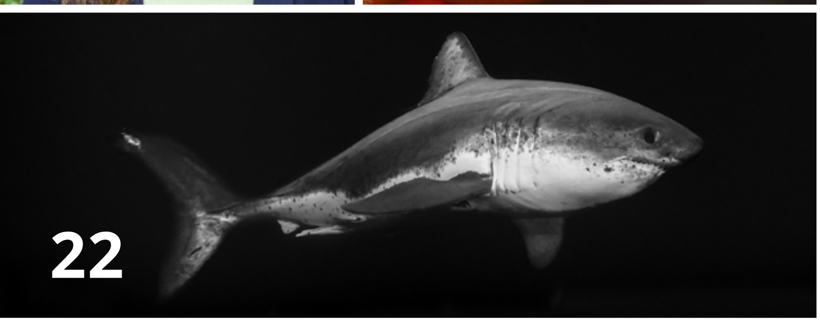
During the last two years of the former Federal administration, three pieces of legislation were passed that contained significant funding for research: the Infrastructure Relief Act (IRA), the Bipartisan Infrastructure Law (BIL), and Disaster relief funding. CICOES was one of seven Cooperative Institutes that received funding under these programs and approximately 30 new projects are now underway. This funding is scheduled to continue over the next three years and will collectively amount to over 80% of the average CICOES funding year. Congratulations to all those that are involved in these programs and we look forward to hearing your results.

The 2024 federal election cycle is now complete and there will be changes in all branches of the Federal administration. There is uncertainty with any change and if the 2016–2020 government is a reliable example, then unpredictability may well be one of the few predictable trends over the next four years. As a research community, we must continue to adapt and take advantage of opportunities as they arise. The integrity and value of our science is independent of which party is running the Federal government. Perspective and policies may shift with administrations but that should never limit how we contribute to the collective knowledge in our fields.

I want to make sure that I thank all those that helped put together this year's CICOES magazine. The editorial and production team changed this year with Jed Thompson's transition to a new job. A big shout-out to all article authors and producers, proofreaders, graphic designer Cathy Schwartz, and editor Thomas Van Pelt.

John K. Horne
Executive Director

"The integrity and value of our science is independent of which party is running the Federal government. Perspective and policies may shift with administrations but that should never limit how we contribute to the collective knowledge in our fields."



Contents

Tracking Ice Islands in the Arctic Ocean

—by Ignatius Rigor (UW/CICOES), Ben Cohen (UW/CICOES), John Woods (Office of Naval Research Global), Cy Keener (University of Maryland), and Adrienne White (Canadian Ice Service)

Scientists surveying, sampling, and placing GPS tags on icebergs trapped in the landfast sea ice near Utqiagvik, Alaska. Local residents with a sled dog team were also present, marveling at the size of these icebergs. The iceberg in the foreground rose 6 meters above the sea ice, and was grounded in 9 meters of sea water.

INTRODUCTION

Icebergs have been part of the mélange of Arctic sea ice since the Arctic Ocean formed 50 million years ago. These icebergs calve off from ice sheets that have grown over millennia through the deposition of snow onto land. When these sheets extend out onto the ocean to become tide-water glaciers, they eventually break up, forming icebergs that drift away, propelled by a combination of winds and ocean currents. The origins of the word “iceberg” translate to “ice mountain,” and icebergs truly are massive: typically over 30 meters thick and 500 square meters in surface area, and often reaching much greater sizes. Some of the largest icebergs have completely flat surfaces; these are called “ice islands.”

The retreat of Arctic sea ice is improving access to natural resources, opening shorter shipping routes between Europe and Asia, and enabling expansion of tourism; all of this is driving dramatic increases in vessel traffic on the Arctic Ocean. Although the extent of Arctic sea ice has declined, and remaining ice is generally thinner, especially during

Photo: Ignatius Rigor

summer, icebergs do continue to pose a significant threat to navigation. The catastrophe of the RMS *Titanic* motivated the creation of the International Ice Patrol in 1914, mandated to monitor icebergs in the North Atlantic—but currently there is no similar international agency with a mandate to monitor icebergs in the rest of the Arctic Ocean and its peripheral seas.

In an ongoing effort to fill this monitoring gap, our multi-institution and multi-disciplinary team, centered around the International Arctic Buoy Program (IABP), has been conducting iceberg research in the Arctic Ocean and Alaskan seas since 2020. In line with the key NOAA initiative of building a "Climate Ready Nation," here we offer context and insights into our work and our expeditions to tag and track icebergs and ice islands.

BRIEF HISTORY

The ice sheet on Greenland provides most of the icebergs in the northern hemisphere, and especially in the North Atlantic. Ellesmere Island west of Greenland is probably the next largest source providing most of the ice islands drifting on the Arctic Ocean. After the Second World War, renewed interest in the Arctic motivated the Former Soviet Union (FSU) and the US to establish drifting research stations on the Arctic Ocean, and ice islands were ideal foundations to set up camps. Aerial reconnaissance first enabled location of ice islands in the 1950s and 60s, and then the advent of satellites in the 1970s made detection of ice islands easier and greatly improved documentation of the drifting paths of ice islands. For example, between 1952 and 1978, "Fletcher's Ice Island," or iceberg T-3, was used as a staffed scientific station and was recorded making three large loops in the Beaufort Gyre before eventually drifting out of the Arctic Ocean through Fram Strait and into the North Atlantic in 1983. At least five of the FSU North Pole Stations were also established on ice islands.

More recently, renewed interest in the natural resources that are becoming more accessible, and aims to cooperate in the Arctic while maintaining national sovereignty, motivated the establishment in 2020 of the International Cooperative Engagement Program for Polar Research (ICE-PPR), a collaboration among allied Arctic nations to support research and improve our operational capabilities in the Arctic.

RECENT FIELD WORK

In the Spring of 2021, we were surprised to hear reports of icebergs locked in the landfast sea ice near Utqiagvik, Alaska. The IABP and its contributors in the USA (the United States Interagency Arctic Buoy Program, USIABP) had been preparing for the ICE-PPR Iceberg Tagging Experiment (ITEX) in Disko Bay, Greenland, and this news posed a serendipitous opportunity to test our new "microbuoys." The USIABP tagged 15 of these icebergs using snowmobiles provided by the National Science Foundation through Ukpeaġvik Iñupiat Corporation Science (UICS), and an S-92 helicopter provided by the North Slope Borough (NSB) Search and Rescue. After the break out of the landfast ice away from Utqiagvik, these icebergs mostly drifted to the west with the Beaufort Gyre, and eventually drifted south through Bering Strait in December 2021 (potentially dragging and destroying some oceanographic moorings that were lost in the shallow strait that year).

Given the success of our new microbuoys and what we learned from tagging the icebergs near Utqiagvik, in August 2021 we flew into Aasiaat, Greenland, to board the Royal Danish Navy patrol vessel HDMS *Einar Mikkelson* for the ICE-PPR ITEX in Disko Bay. During this cruise, we tagged 58 icebergs ranging in size from small 5-meter "growlers" to ice islands 500 meters across. We were able to use small

Photo: Ignatius Rigor

Ice Island DSE 13 as seen from the Uncrewed Aircraft Vehicle (UAV, or "drone") that was used to survey the iceberg on August 17, 2021. The Danish naval patrol vessel HDMS *Ejnar Mikkelsen*, from which the UAVs were flown, can be seen in the background. HDMS *Ejnar Mikkelsen* is 72m long, while DSE 13 was 70 meters tall and 480 by 340 meters across.

Photo: Ignatius Rigor

Ice Island DSE 13, with a deployed "Spider" GPS tag visible in the center-right foreground, as the HDMS *Ejnar Mikkelsen* cruises by.

boats to place tags on the free-floating icebergs, and we also used Uncrewed Aerial Vehicles (UAVs, commonly known as drones). Our UAVs for that expedition were developed as a remote student project during the COVID-19 pandemic by Kushal Kedia, a former summer high school intern at the UW Applied Physics Laboratory.

In August 2021, the USIABP worked with the Royal Canadian Air Force (RCAF) and the Canadian Ice Service (CIS) to tag six ice islands north of the Canadian Archipelago as part of ICE-PPR. In contrast to tagging icebergs from ships that may have to break through the sea ice to reach an iceberg, aircraft can fly unhindered to our targets and cover a broader area in a much shorter amount of time (hours, versus weeks). During the next two years, these islands drifted slowly to the west into the Beaufort Gyre, but power for our tags is limited and all six ceased to report in 2023.

Given that these ice islands were drifting from Canada into US waters and given the dangers that these ice islands posed to navigation, the USIABP worked with the CIS to manually track these islands via continual analyses of satellite imagery. Our team then tried to re-tag them in October 2023 using a US Coast Guard C-130 from Kodiak, Alaska. As with all field work, the best-laid plans need to be flexible. A fuel leak delayed this flight light for one week, and the ice islands drifted out of range of our planned flight. The next opportunity to tag these islands came in January 2024. The USIABP and ICE-PPR began flying with the 144th Squadron of the Alaska Air National Guard (AK ANG) in 2023, with plans to reseed the IABP observing network, and tagging these islands was imperative. This effort required arduous tracking of the ice islands by the CIS, US National Ice Center (USNIC), and the NOAA Alaska Sea Ice Program (ASIP) using all available satellite images, and the team continued to scour the latest satellite images in the weeks and hours leading up to the flights.

On January 21, 2024, we had our first solid chance to locate and re-tag these ice islands. January is the middle of the polar night; we had some twilight, but visibility was low and learning how to use the ground radar on the C-17 aircraft to visualize sea ice was a challenge. As we approached the expected position of the awkwardly named "MIL20-A-1-B-3-A" ice island, we finally realized that the signature of the ice islands on the radar was a bright green leading edge, with a dark shadow behind it. This signature was 10 miles off from where we expected the ice island to be, based on forecasted winds and the most recent satellite imagery that we could obtain in the morning before the flight. Again, our plans changed and we altered course for this new position.

Luckily the clouds cleared and we got visual confirmation when we flew over the island, so we circled back and tagged the island with one of our larger "ICEXAIR" buoys that should report for about four years. We learned a lot from this experience and were eager to tag more icebergs during our next flights with the AK ANG in August 2024. The challenge over the Arctic Ocean during summer is the persistent low stratus clouds that mostly form from steam fog wafting up from the cracks in the sea ice. Oddly, visibility during the polar night was better. Despite the multiple challenges, we were able to tag three more ice islands, and dropped a second buoy on MIL20-A-1-B-3-A.

The data from the buoys is provided to the National Weather Service and other operational weather and ice forecasting agencies through the WMO/IOC GTS. These data will also help us answer a myriad of scientific questions such as, can we predict the drift of these ice islands? Although there has been some work on the force balance of drifting icebergs, much of this research is from the Southern Ocean where the winds and ocean currents tend to flow in the same direction, and most of the research in the Arctic Ocean was from decades ago when there was lots of older, thicker sea ice. Satellite images will also help us document changes in iceberg size, while the temperature sensors on these buoys will help us quantify surface ablation. Other IABP buoys on sea ice near the islands and in the ocean around them will help us quantify bottom melt.

> *"January is the middle of the polar night; we had some twilight, but visibility was low and learning how to use the ground radar on the C-17 aircraft to visualize sea ice was a challenge."*

Photo: Ignatius Rigor

Iceberg VSO 17, photographed from a drone flying directly above. This iceberg was 70 m tall and about 160 m in diameter, and was classified as a "dry dock" given the enclosed calm water in the center.

CONCLUSION

Vessel traffic in the Arctic is increasing. Although there is less sea ice overall, remaining ice moves faster in response to wind, and many other hazards still exist such as the ice islands described in this story. As we strive to build a "Climate Ready Nation," monitoring and being able to predict the drift and fate of these ice islands is critical for navigation, commerce, and safety at sea. As noted earlier, at present there is no international agency with a mandate to track icebergs in Alaskan waters and the Arctic Ocean. Our current efforts to advance our capabilities to predict iceberg drift are built around an ad hoc team (USIABP, USNIC, ASIP, CIS, etc.), and in an ideal future, sustained support for monitoring and tracking icebergs would be provided to a dedicated operational agency.

ACKNOWLEDGMENTS

The US Interagency Arctic Buoy Program (USIABP) is co-managed by APL/UW and the National Ice Center (USNIC), with support from the NOAA Arctic Research Program, National Weather Service, NESDIS, and other US agencies, including the Office of Naval Research and the National Science Foundation. We thank the AK ANG, RCAF, UICS, and NSB-SAR for their support, and we thank ICE-PPR and the participants of the IABP who have contributed to this effort. ■

Photo: Sarah Smith, University of Washington

YAKELYN RAMOS JAUREGUI, CICOES postdoc, aims to improve accuracy of weather and climate predictions

—by Michelle Ma,
UW College of the Environment

Growing up in a farming family in Peru's central Andes highlands, Yakelyn Ramos Jauregui's fascination with weather and climate began early.

When El Niño and La Niña cycled through her hometown of Huancayo, Jauregui saw the wide-ranging impacts on her family's crops. Many Peruvian communities like hers rely on agriculture for economic stability. The lack of accurate weather forecasts—and unpredictable weather events, like severe storms and prolonged droughts—can be devastating for livelihoods and communities.

Jauregui's desire to improve weather and climate prediction for families like hers fueled her academic path, which took her from Peru to Seattle.

We sat down with Jauregui at the culmination of her doctoral studies in atmospheric and climate science—and as she continues her science career as a postdoc in the same field—to hear firsthand about her journey.

What got you interested in weather and climate, specifically?

I grew up on a farm in Peru. My grandparents are farmers, and farming depends heavily on weather conditions—every crop has specific moisture and temperature needs, for example.

As a child, during family dinners, I would observe my family expressing their frustration when their crops failed due to early rains or extended droughts that weather forecasts and seasonal outlooks hadn't predicted. Those crop failures often left them financially unprepared, a situation shared by farmers around the world.

If you're expecting rain to support what you planted, and instead your region experiences a prolonged dry period, that can be disastrous for your family—not to mention for all the communities who rely on farming for income and food. And you know, eventually, most of us can thank farmers for the food at our tables, so these impacts can have far-reaching consequences.

And in college, you wanted to study a field that had clear connections to the kinds of problems your grandparents faced?
Yes, exactly! My grandparents are retired now, but Peruvian farmers still face similar challenges. Climate change is making the rainy and dry seasons less predictable, and changes in El Niño and La Niña's behavior are partly responsible for these challenges in weather and seasonal prediction. I knew that I wanted a career where I could help my grandparents and Peru's farmers adapt to weather events associated with El Niño and La Niña, and ultimately to climate change. In Peru, the only school that offered a career in meteorology was the National Agrarian University in Lima, our capital. That's why I moved from the dry mountains to the humid coast, where the weather and climate are very different from what I was used to!

Did you know what you'd do with the degree?
I was on track to become a weather forecaster. I only knew of one career path at the time: working at a weather forecast center in Lima or in my hometown, Huancayo. However, my journey took an unexpected turn when I attended a small workshop at the university where climate scientists came to present their work. That's when I first met Ken Takahashi Guevara, a scientist who worked for the Instituto Geofísico del Perú (Geophysical Institute of Peru). He gave a talk about El Niño, and I realized that he was doing exactly the kind of work I had always dreamed of—work that could satisfy my curiosity about understanding the world. Meeting him marked a pivotal moment in my career.

That must have been exciting!
It really was. At the time, Ken studied how rainfall associated with El Niño and La Niña, known as the El Niño-Southern Oscillation (ENSO), affects different regions in Peru, like the Andes and coastal regions. He made the science very simple and easy to understand. That was when I decided, I want to be a scientist, to do what he's doing— understanding new information and passing along what I learn to people who can use it.

Can you talk about the additional barriers that language can create in the sciences?
One of the first things that Ken told me was, "If you want to do science, you'll be very good at it, but you have to learn English." In our field, most papers are in English; you have to write and read very technical information in English. Back then, I needed several weeks to translate and understand a single paper. Nowadays, it's a bit easier because we have Google Translate; the translation might not be 100% accurate, but it is fast.

I learned English in my early 20s, and I have to make extra effort to pronounce words correctly so that I can get my work across. It takes me longer to improve my speaking and writing skills. But my doctoral adviser and research group helped me improve my communication skills, which makes me feel more confident as a scientist.

Red quinoa field, Andean highlands, Peru.

Photo: cicloco at iStockphoto.com

"Each time I learn something new, it leads to another "why," pushing me to keep exploring… I used to believe that my questions would eventually come to an end, but now I realize the journey of curiosity is endless!"

When did you decide to apply to graduate school?

After working for four years as a research assistant with Ken at the Geophysical Institute of Peru, I felt that my scientific career had stalled. I needed to learn new skills and pursue an advanced degree, but at the time it wasn't possible in Peru.

It was Ken who encouraged me to apply to graduate school abroad. He had also received his doctoral degree in atmospheric sciences at the UW, which helped him become a leading climate scientist in Peru. It took me a year to prepare for exams, but my hard work paid off.

How would you describe your experience here as a graduate student?

I had an awesome experience! I was nervous about coming to a new country, but I've always had positive experiences in my field.

The UW has a vibrant and diverse environment, and my experience was amazing, especially working with my doctoral adviser, Shuyi Chen. She is a great mentor and has a huge network of collaborators.

Shuyi encourages me to travel to workshops and conferences where I can learn and exchange my ideas with other scientists. Because of Shuyi, I've been able to develop my career, build strong connections in the scientific community and work on exciting projects related to my research interests.

You've mentioned El Niño and La Niña. Is that what you studied as a doctoral student?

Originally, I wanted to improve El Niño predictions, particularly in its early-stage development. To achieve this, I studied a phenomenon called the Madden-Julian Oscillation (MJO). The MJO can influence the early development of El Niño and sometimes even help trigger it. My goal was to understand how these two different phenomena interact.

How would you describe the Madden-Julian Oscillation to someone without a science background?

The Madden-Julian Oscillation is a system made up of extensive convective clouds—the kind that look like giant stacks of cotton balls. Over about four to five weeks, it travels east from the Indian Ocean to the western Pacific Ocean. As it travels, it generates very heavy rainfall and strong winds.

The Madden-Julian Oscillation isn't familiar to most people, but it has an impact on global weather and climate that's just as significant as El Niño. So, there I was, a new doctoral student, studying some of the most important phenomena in the tropical meteorology. With thousands of scientists already working on these topics, contributing anything new was daunting—it often felt overwhelming, even impossible at times.

What prompted you to focus on the effects of rainfall from the Madden-Julian Oscillation?

So, heavy rains can have a significant influence on the ocean's surface, specifically on its salinity, currents, and temperature, because they dump a lot of freshwater into the sea. Historically, we lacked data to study the impacts of MJO rainfall on its interactions with El Niño. We only knew that rainfall was an important player at all because of a massive field effort in the early 1990s.

Where did you access the data that made it possible to investigate MJO rainfall?

Satellites! When I started my PhD in 2017, we had close to 20 years of precipitation data from satellites that provided new insights into the amount, intensity, and concentration of rainfall from Madden-Julian Oscillations. Once I had that data, I could study the connection between how and when rainfall affects sea surface temperature as the MJO travels from the Indian Ocean to the western Pacific.

Did you learn anything new?

Absolutely! We had two exciting findings that resulted in publications. First, we discovered that after MJO rainfall ends, the ocean surface not only warms significantly but also continues to warm and expand eastward for several weeks.

We also learned about how MJO rain contributes to the movement of warm water from the western Pacific toward the central Pacific. The details are pretty technical, but essentially, we discovered that rain can influence the direction of travel for surface-level ocean currents. And in this case, MJO rainfall can make currents flow east—sometimes against the wind—from March to May, which is a time when they might play a critical role in the development of El Niño.

“While we still have more to learn, down the road our research could improve long-range forecasts—and that could help farmers better prepare for the combined impacts of these weather and climate systems.”

And that information might help people like your grandparents someday?

Yes, that’s the goal! That March to May period is when current forecasting models struggle to make accurate global predictions that could help farmers. While we still have more to learn, down the road our research could improve long-range forecasts—and that could help farmers better prepare for the combined impacts of these weather and climate systems.

What’s next for you?

I am currently a postdoctoral researcher at CICOES, where I work with Chidong Zhang from NOAA’s Pacific Marine Environmental Laboratory. I’m also continuing my collaboration with Shuyi.

One of the projects I’m involved with is a major international field campaign scheduled for 2026–27 called the Tropical Pacific Observing Experiment. The goal is to better understand and observe interactions between the air and ocean during the Madden-Julian Oscillation. It’s thrilling to see that my doctoral work has inspired and contributed directly to this proposed field campaign, and I’m learning a great deal from this experience. Working alongside well-known oceanographers and atmospheric scientists is a great experience. It feels like I am living a dream!

Looking ahead, I aim to focus more on high-impact weather prediction and projection, incorporating machine learning tools into my skillset. I would love to continue my collaborations both in the U.S. and Peru; as a scientist, my goal has always been to advance knowledge that supports communities, both locally and globally. ▪

Photo: Yuji Kashino, RIGC/JAMSTEC

A storm preluding a Madden-Julian Oscillation event over the tropical Indian Ocean.

Photo: Courtesy of Yakelyn Ramos Jauregui

Yakelyn Ramos Jauregui (center) with colleagues at the AGU (American Geophysical Union) meeting in 2024; from left to right: Shuyi Chen (UW), Chad Small (UW graduate student), Benjamin Barr (WHOI), Edoardo Mazza (CICOES research scientist), Richard Zhuang (UW graduate student), Alton Daley (UW graduate student), Nan-hsun Chi (CICOES research scientist), and Chidong Zhang (NOAA PMEL).

Pacific Hake Distribution Forecasts:

Supporting Adaptive Fisheries Management

—by Jake Marshall (OSU), Mary Hunsicker (NOAA NWFSC), and Lorenzo Ciannelli (OSU)

Pacific hake are economically and ecologically important fish that mainly reside in waters over the western continental slopes of the U.S. and Canada. The coastal stock of Pacific hake is the most abundant groundfish in U.S. Pacific waters outside of Alaska. In 2021 alone, the hake fishery was responsible for a total economic impact of US$335 million and supported 4,450 jobs in the northern U.S. West Coast. But recent anomalous environmental conditions, including warming marine waters, have caused unforeseen shifts in hake distribution, limiting the proactive work of fishery managers and resulting in significant impacts to recent hake harvests.

These recent changes highlight the critical need within the hake fishery for "actionable science"—specifically, ecological modeling products that inform future fishing and management strategies, supporting an adaptable and sustainable fishery. To this end, our team of CICOES-affiliated researchers has joined forces to produce forecasts of hake biomass (weight of fish in a given area of ocean) along the U.S. and Canadian coasts. We used outputs from ocean forecasting models to generate pre-season forecasts of hake biomass distribution during the upcoming fishing season.

In this article, we will walk through the modeling framework and showcase our initial hake biomass distribution forecasts. We also provide a few maps and plots to visualize the modeled distribution shift in 2024 as compared to 2023. We will wrap up by discussing these models' limitations, and by highlighting future directions for our work.

FIRST, SOME BACKGROUND:

- Hake is a migratory fish species. Hake winter in their spawning grounds off the coast of Southern and Baja California. In summer, hake are found in their feeding grounds ranging from central California through British Columbia, where they are commercially harvested. Throughout this season, older hake typically occupy areas farther north than younger ones, while all age groups remain concentrated along the continental shelf break.
- Temperature affects summertime hake distributions. Temperature has been shown to shape where hake can be found and how many are there. Additionally, temperature affects hake differently depending on their age, complicating efforts to predict their distributions. Shifts in hake distribution are likely happening due to a variety of reasons, though the main hypothesis is that hake distributions follow their key food sources, such as krill. Together, these factors lead

Photo: Jeff Bash, NOAA Fisheries, Northwest Fisheries Science Center to shifts in where hake gather, which can greatly impact their commercial harvest.

- Recent studies predict future ocean temperature increases. The Northeast Pacific Ocean has recently seen an emergence of marine heatwaves (MHWs)—large areas of ocean with much warmer temperatures than normal. State of the art models forecast that MHWs will become more frequent and intense in the future. Given that temperature is a crucial factor influencing hake distributions, we expect that hake will increasingly shift away from their historical feeding grounds as the coastal North Pacific waters continue to warm.
- Shifts in the distribution of hake are likely to affect fishing productivity, efficiency, and non-target catch rates. During the 2023 fishing season, a dramatic decrease in hake catches north of the U.S.-Canada border led to Canada's least productive hake season in more than two decades. Additionally, studies indicate that unusually warm ocean conditions are associated with increased incidental catch of non-target species in the hake fishery, such as chinook salmon. These combined factors make it challenging for fisheries to efficiently locate hake while minimizing the capture of unwanted species, potentially reducing fishing efficiency and complicating efforts to protect endangered species.

WHERE ARE HAKE HEADED?

To help fishery managers predict where hake are likely to be found in future seasons, we developed a modeling framework to forecast Pacific hake biomass distributions up to seven months into the future. Because migration patterns change as hake age—older fish tend to travel farther north than younger fish—our framework includes independent models for four different age groups of hake: total population, age 2, ages 3–4, and ages 5 and older ("5+", up to a maximum age of about 15 years). We used these models to predict the amount of hake that annually migrate north of the U.S.-Canada border. We then provided a geographical overview of the forecasted shifts in hake distribution, showing exactly where their numbers are predicted to increase and decrease. By understanding how these age groups of hake are likely to move in response to temperature changes, fisheries managers and industry stakeholders can gain crucial insights into hake movements. This knowledge could be invaluable, enabling better planning and more informed decision-making in the fisheries sector.

HERE'S HOW WE DID IT, STEP BY STEP

Step 1: Train the models on past data

Method: We used statistical models to explore how changes in ocean temperature affect hake populations. The data we used came from the Joint U.S.–Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey for every survey conducted from 1995 through 2023. We used forecasts of subsurface temperatures from the JISAO Seasonal Coastal Ocean Prediction of the Ecosystem (J-SCOPE) as our main dynamic environmental variable. These temperature forecasts, along with other key environmental data, were aligned with the times and locations of the hake observations. This setup allowed us to study how predicted environmental changes might influence hake numbers in different age groups, as shown in Figure 1.

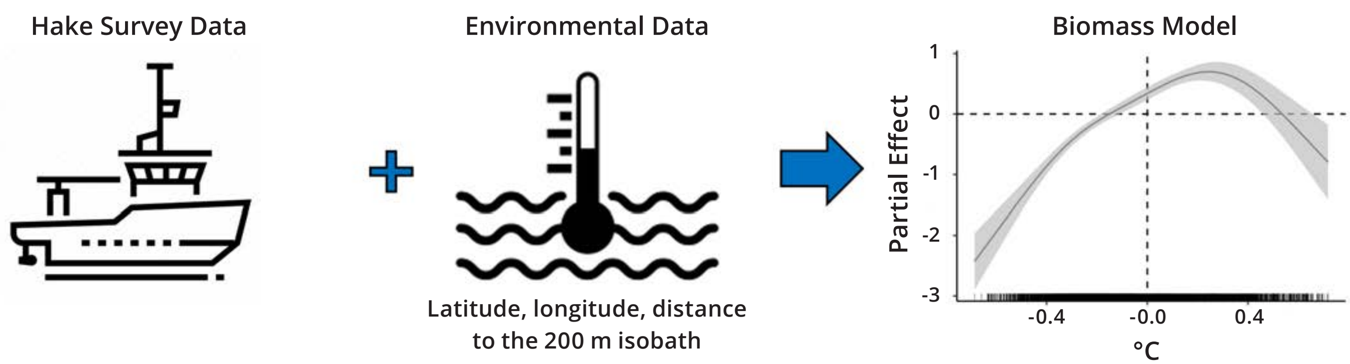


Figure 1. Visualization of training a hake biomass model.

Results: We discovered that temperature plays a crucial role in determining where hake are found, affecting all age groups. Temperature consistently emerged as a key predictive variable in our models for identifying the distribution patterns of hake among different age groups.

Step 2: Predict biomass distributions for 2024

Method: Using statistical models like the one developed in Step 1, we can make predictions of hake biomass under environmental conditions forecasted for later dates (Figure 2). We applied these models in conjunction with the environmental forecasts to predict the distribution of hake biomass for each age group of hake for August of 2024 (Figure 3).

Results: As expected, forecasts predict the majority of hake biomass around the shelf break, with older hake residing farther north than younger hake (Figure 3). Age 2 hake forecasts show a large hotspot in the southern region from (43–44ºN), age 3-4 hake forecasts show significant biomass predictions around the shelf break south of Gray's Harbor (46.5ºN), and age 5+ hake forecasts show similar patterns as age 3–4 but with a northern hotspot around the U.S.–Canada border (48.5ºN) (Figure 3).

Step 3: Calculate the U.S.–Canada hake ratio

Method: We calculated the predicted ratio of hake biomass in U.S. waters to the total hake biomass, referred to as the "U.S.–Canada ratio". To assess the accuracy of our models in predicting the northward shifts of hake across the U.S.–Canada border, we compared our model forecasts to actual observations. We began by calculating the ratio of hake observed during the acoustic survey that remained in U.S. waters. Next, we found the ratio of hake that were predicted to remain in U.S. waters. To evaluate how closely our predictions matched the observations, we plotted the predicted and observed U.S.–Canada ratios on the same graph. This comparison was conducted over the last seven survey years.

Results: Our models were not consistently accurate at predicting the U.S.-Canada ratio during past years. Figure 4 shows the U.S.–Canada ratio, which aims to show the shift of hake biomass across this border from year to year. A value of 1 means all hake are in U.S. waters, while a value of 0.5 means there are equal numbers in U.S. and Canadian waters. The four plots in Figure 4 show the observed ratio (black line) and the predicted ratio (blue line) across the retrospective period, for all hake in total and for each of the three age groups.

The accuracy of the model for each year can be seen as the vertical distance between the observed and predicted lines. A highly accurate model would show the predicted U.S.–Canada ratios (blue line) very close to the observed ratio (black line). Our model predictions were moderately accurate for the first two and last two years, but not so accurate for the anomalously warm years of 2015, 2017, and 2019, shaded in red.

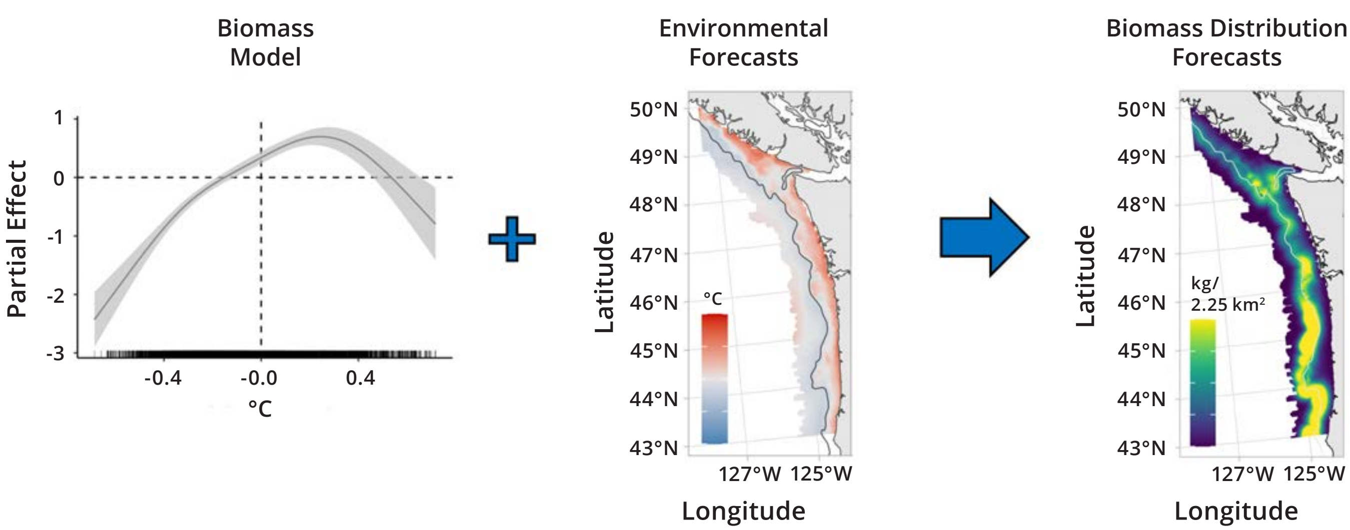


Figure 2. Visualization of the process of forecasting hake biomass distribution, using a trained hake biomass model and ocean temperature forecasts.

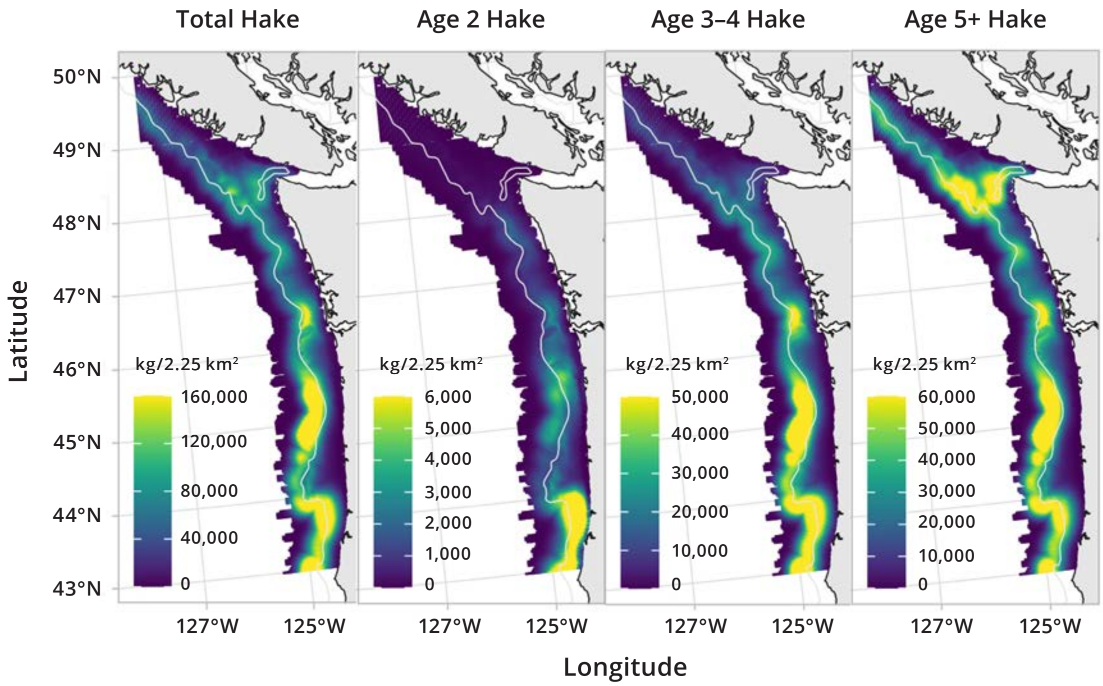


Figure 3. Predicted hake biomass distribution of each age group for August 2024. The white line represents the continental shelf break (200-meter isobath).

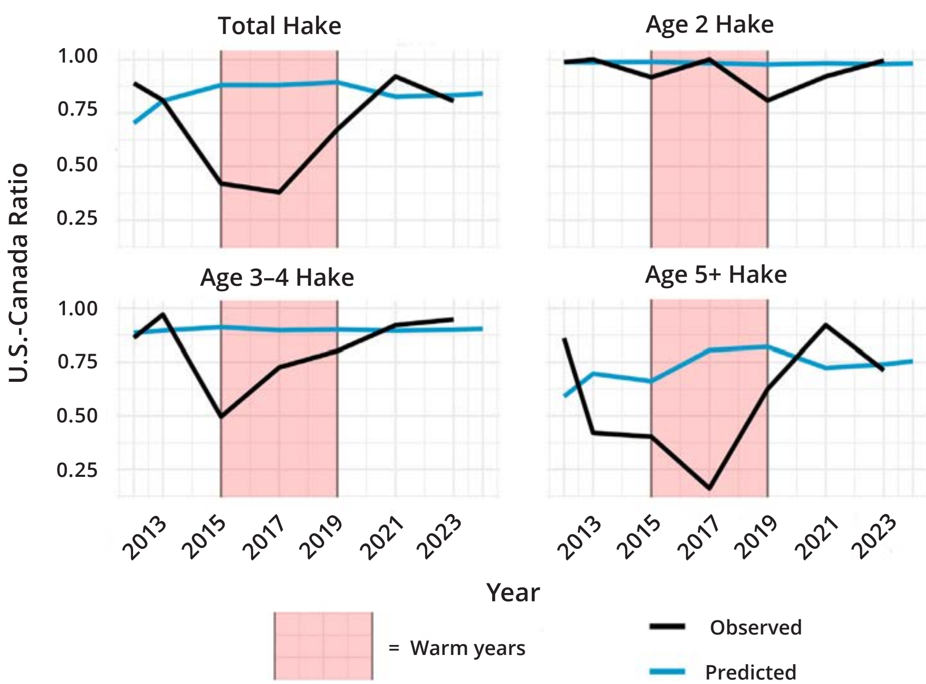


Figure 4. The ratio of hake in U.S. waters to all hake in the study region, referred to as the "U.S.–Canada ratio." The ratio observed on the hake survey is shown by the black line, and the ratio predicted by the biomass models is represented by the blue line. Higher ratios indicate a relatively greater presence of hake in the U.S. compared to Canada; a value of 1 means all hake are in U.S. waters, while a value of 0.5 means there are equal numbers in U.S. and Canadian waters. Years with anomalously warm ocean temperatures are highlighted in red.

Crucially, the ocean conditions and hake distributions observed during those anomalous years were unlike any conditions found in the training data. Since these models make predictions based on relationships observed in the past, poor model performance during the unprecedented conditions of 2015, 2017, and 2019 is understandable. At the same time, this result highlights the challenge facing fishery managers in coping with increasingly novel environmental conditions in an uncertain future.

Step 4: Find how the predicted distribution for 2024 compares to the past

Method: Our initial models failed to accurately capture how hake populations were moving into Canadian waters. To uncover what was really happening, we compared our predictions for 2023 and 2024 to trace spatial shifts in hake distribution. Using this method, we can see specifically where hake are predicted to increase in quantity and where they are expected to decrease.

Results: Hake numbers are predicted to decrease in deeper, offshore areas and along some coastal stretches (Figure 5, blue areas). Conversely, significant increases are expected on the inshore side of the shelf break (Figure 5, red areas). Note that these predicted changes are not uniform across age groups. Younger hake are predicted to experience significant increases along the shore, while older hake may see only slight increases or even decreases in the same areas. Finally, we see a minimal latitudinal shift across age groups, consistent with the small change in the U.S.-Canada ratio forecasted in Step 3.

LIMITATIONS TO OUR ANALYSIS

While our models provide valuable insights into hake biomass distributions, we need to acknowledge several important limitations. Firstly, the spatial coverage of these forecasts is currently limited. These biomass distribution forecasts do not currently cover the entirety of hake fishing grounds, including areas of importance to the hake fishery such as the proposed offshore wind farms off the Oregon coast. Second, these predictions represent relative amounts of hake biomass, not the exact numbers. Although the models show the distribution of hake

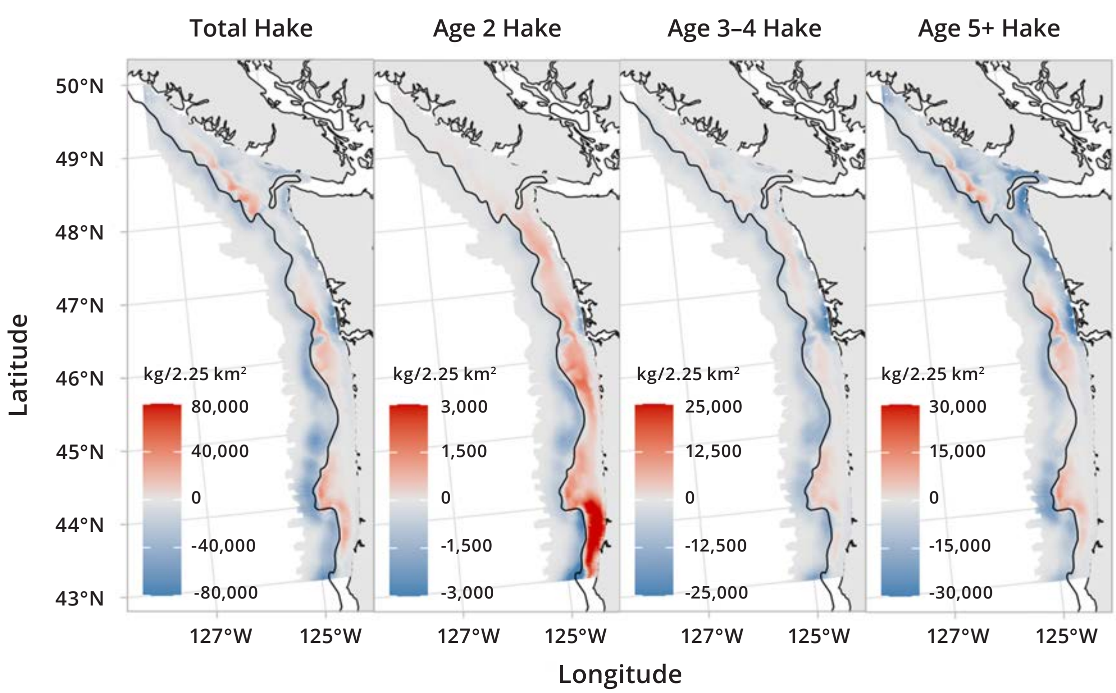


Figure 5. Change between the 2023 and 2024 biomass distribution predictions. Red indicates regions with predicted increases in hake biomass and blue indicates regions with predicted decreases. The color bars are scaled at 1/2 those of the respective age forecast maps in Figure 3. The shelf break is shown in black.

as weight (kg) along the coast, they are more useful for tracking relative changes in how much hake there is from one place to another or from one year to the next. For instance, these models should not be used to specify the exact weight of hake in a certain area. Instead, the predictions should be seen as indicating trends in how hake biomass varies across different areas and over time, as shown in figures like Figure 3 and from year to year in Figures 4 and 5. Finally, temperature was the only environmental driver used in this study. Although other variables such as dissolved oxygen and the California Undercurrent velocity have been seen to influence hake distributions, we focused our efforts on informing biomass forecasts with temperature alone.

WHAT'S NEXT?

Our research marks an important first step toward gaining a clearer understanding of how hake populations are responding to warming ocean waters. Looking ahead, we see potential to improve our hake biomass distribution forecasts by expanding the range of environmental factors we consider. Our models, which are now driven solely by temperature, were only moderately accurate in predicting latitudinal shifts in hake distribution. Incorporating additional variables, such as dissolved oxygen concentrations, prey abundance, and subsurface current speed, could strengthen these models and increase their accuracy.

Fortunately, forecasts of these additional environmental variables should be available in the very near future. NOAA and the Northwest Association of Networked Ocean Observing Systems (NANOOS) are enhancing regional ocean models, increasing the spatial coverage to include the whole U.S. and Canadian West Coast. Our modeling framework can be easily modified to include these upcoming enhanced environmental forecasts, increasing both the spatial range of our models and their predictive accuracy. We aim to create a more robust and adaptable modeling framework that can better inform hake fishery management and operations along the U.S. and Canadian West Coast— stay tuned for our next steps! ■

The authors would like to thank Michael Malick, Lori Cramer, Amanda Gladics, and the Fishery Resource Analysis and Monitoring Division at NOAA for their help in this project.

Photo: Mike Atkins

Hauling catch of Pacific Hake off the coast of British Columbia on the F/V *Ocean King* in February, 2024.

Photo: NOAA Fisheries/Jessica M. Lindsay

FROM ICE FLOES TO OPEN WATERS

Charting a future for protected species in a warming Alaska

—by Elizabeth McHuron (CICOES), with contributions from Dana Wright (CICOES) and NOAA collaborators at the Alaska Fisheries Science Center

Above: NOAA researchers conduct ice seal captures from small inflatable boats deployed from the R/V *Norseman II* .

What do right whales and ribbon seals have in common?

To the keen eye of my 7-year-old, their shared characteristics include flippers, black and white coloration, and a home in the ocean. Their similarities go deeper, though, because ribbon seals and the North Pacific species of right whale both inhabit a region that is at the forefront of climate change.

Air temperatures in Alaska are warming at a rate that is nearly 50% greater than the rest of the U.S. Warming air is driving corresponding declines in sea ice, a key physical feature of Alaska's marine ecosystems and one that is integral to the lives of right whales and ribbon seals. In the past decade alone, Alaska has experienced several marine heatwaves and an anomalous period of record low sea ice, with wide-ranging and lasting impacts on marine ecosystems, coastal communities, and fishing industries. End of century projections indicate continued warming and declines in biomass of key prey species, suggesting that recent events likely provide a window into the future for Alaska's biological communities.

Climate change has been identified as a central threat to both North Pacific right whales and all Alaskan ice-associated seals, a group of four species (ribbon, ringed, bearded, and spotted seals) whose life history is intimately tied with ice. North Pacific right whales have been listed as “endangered” under the Endangered Species Act (ESA) since the 1970s, as populations have failed to recover from commercial whaling that nearly extirpated the species. With an estimated fewer than 50 individuals left in the eastern population and roughly 500 individuals across the entire species' range, North Pacific right whales are one of the rarest baleen whales on the planet and considered “critically endangered” by the IUCN red list.

CLIMATE CHANGE CONCERNS

Known climate-related concerns for right whales primarily center around adverse effects on their planktonic prey, which during recent warm years have shifted northwards and were dominated by smaller, less fat-rich species. The loss of sea ice for resting and reproduction is the primary concern for ice seals, which was the basis of petitions to NOAA for listing all four species under the ESA despite their relatively high abundances (populations of ringed and bearded seals were ESA-listed as “threatened” in 2012). Additional climate-change concerns for right whales and ice seals center around a largely unknown quantity, which is how the potential for increased human activities in Arctic waters—due to greatly expanded accessibility with shrinking sea-ice cover—could directly (e.g., through ship strikes) or indirectly (e.g., oil spills) affect these species.

> *“Understanding marine mammal responses to climate change is a vital part of ecosystem-based fisheries management and ecosystem-based management more broadly.”*

Despite clearly identified general concerns, we still know little about current or future impacts of climate change on right whales or ice seals in Alaskan waters. Conducting research on these species is an exercise akin to searching for a needle in a haystack. Both species occur across vast and remote habitats, making research difficult and costly, with the added challenge that sightings of right whales are extremely rare (there have only been 115 confirmed sightings across the entire North Pacific since 2004). What we do know—based on research conducted during the recent warm events in the Bering Sea—is that ribbon seals and spotted seal pups were in poorer condition and that right whales may have experienced more short fasting bouts, although this is still being investigated. Research from other areas or closely related species, such as the more well-studied North Atlantic

Two North Pacific right whales (*Eubalaena japonica*) spotted in the Gulf of Alaska from the NOAA ship *Oscar Dyson* in 2021.

Photo: Jessica Crance/NOAA Fisheries, photo taken under NMFS Research Permit #20465.

An adult male ribbon (*Histriophoca fasciata*) seal rests on an ice floe after being released by the research team.

Photo: Jessica M. Lindsay/NOAA Fisheries, photo taken while working under authority of NMFS Research Permit #23858.

right whale, suggests that climate-change responses can include shifts in spatial distribution, changes in timing of reproduction and other life history events, and declines in body condition and overall size that can have cascading impacts on population dynamics.

CLIMATE AND ECOSYSTEM SENTINELS

Beyond supporting the direct management of federally protected species like ice seals and right whales, improved understanding of marine mammal responses to climate change is a vital part of ecosystem-based fisheries management and ecosystem-based management more broadly. Indeed, many marine mammal species are considered climate and ecosystem sentinels because they are conspicuous, sensitive to underlying changes in ecosystem processes, and respond in a timely and measurable manner to such changes. Marine mammals can exert large consumptive effects on local prey populations (e.g., zooplankton, fish), in large part because of their high energy requirements. Many species also become prey for apex predators, like killer whales, polar bears, and large sharks. Whales also serve an important role in the transfer of essential nutrients to surface waters—by feeding in one place and urinating and defecating at the surface— that can contribute to the growth and productivity of primary producers (the base of the food web). In Alaska, ice seals, walrus, and some whales, provide vital subsistence resources and are central to the cultural identity of numerous coastal Alaska Native communities.

SAFEGUARDING MARINE RESOURCES IN A CHANGING CLIMATE

In 2022, the U.S. Congress passed the Inflation Reduction Act (IRA), which included $3.3 billion for NOAA to help build the capacity to prepare for, and increase resilience to, weather and climate events. The Alaska Fisheries Science Center in Seattle received IRA funding as part of the Climate, Ecosystems, and Fisheries Initiative (CEFI), a cross-NOAA initiative with the goal of facilitating climate-informed management to safeguard marine resources and resource-dependent communities in a changing climate.

This funding provides support to advance ocean modeling efforts, multi-species stock assessments, and develop climate-informed species distribution models, with the intent of building upon existing research efforts in this region, such as the Alaska Climate Integrated Modeling project. IRA funding was also available through NOAA's Office of Protected Resources for projects that advanced approaches for adaptation and resilience of protected species to climate-related changes. A successful North Pacific right whale proposal was funded through this call, spearheaded by CICOES researcher Dana Wright.

Over the next several years, we (CICOES researchers) and our NOAA colleagues at the Alaska Fisheries Science Center will put IRA funds to work in developing climate-focused research on North Pacific right whales and ice seals. We plan to take advantage of the limited data available for these species, primarily data collected through the use of passive acoustic recorders that “listen” for right whales and telemetry tags glued directly to the fur that allow ice seals to “tell” us where they go. By pairing information on where they like to spend their time (and conversely areas they choose not to be) with the associated physical and biological characteristics of those locations, such as water temperature, we hope to be able to predict where right whales and ice seals might go in the future, and how this differs from the present and recent past.

OCEAN MODELS

One of the key CEFI products that will be instrumental in our work is the continued development of ocean models that use mathematical equations to predict the past, current, and future environment (https://psl.noaa.gov/cefi_portal/). While this sounds (and is) complicated, most of us are actually exposed to the general concept of numerical models every year during hurricane season, unless of course you have never spent time looking at spaghetti plots of hurricane trajectories and wondering what the differences are between the “European” and “American” models. Since we have no way to physically measure something that hasn’t happened yet, ocean models provide a window into the range of potential conditions that right whales and ice seals are likely to experience in Alaskan waters in the coming months, years, and decades.

"...ocean models provide a window into the range of potential conditions that right whales and ice seals are likely to experience in Alaskan waters in the coming months, years, and decades."

EFFORT COVERS REGIONS ACROSS U.S.

Our team is just one small part of a much larger effort that spans seven regions across the U.S., from the East Coast to the Great Lakes to the Pacific Islands. We are at the beginning of what is undoubtedly a long journey, with the ambitious goal of routinely providing the science needed to help promote sustainable fisheries, healthy ecosystems, and resilient communities in the face of climate change. Through such efforts, it is my hope that right whales and ribbon seals will persist despite their rapidly changing environments, not just in photos on the internet—but wild in their natural habitat for my son's generation and many generations into the future. ▪

(top) CICOES researcher Skyla Walcott prepares to release a subadult female ribbon seal (*Histriophoca fasciata*) after a successful sampling procedure. The transmitter adhered to the top of the seal's head provides critical data on her location, diving, and haul-out behavior that can be linked with ocean model outputs to understand how ribbon seals use available habitat and the physical and biological characteristics of high-use and low-use areas.

(bottom) Female ribbon seal with a newly applied transmitter on her head. The transmitter is glued to the seal's fur, not skin, and will fall off during the annual molting cycle.

Photos: Jessica M. Lindsay/NOAA Fisheries, photos taken while working under authority of NMFS Research Permit #23858.

Salmon shark: a misnomer?

Exploring the diet and ecosystem impact of these predators in the California Current Ecosystem

Photo: Ron Watkins

—by Alexandra McInturf (CICOES)

There are few species more iconic to the Pacific Northwest than Pacific salmon.

These fishes are central to ecological processes, offer important economic value, and are the keystone of many cultural practices. As a result, salmon populations have been highly managed for several decades, and there is great concern about ensuring wild salmon persistence.

Many threats that Pacific salmon currently face are well-documented, including habitat destruction, climate change, overexploitation, and the development of human infrastructure like dams. However, over the last several years I have become interested in a less-understood factor that inevitably affects salmon numbers each year: predation. And it was perhaps inevitable that my research focus as a CICOES postdoctoral fellow narrowed to one predator in particular, the curiously named salmon shark (*Lamna ditropis*). Do salmon sharks in our region really earn their name?

SALMON SHARKS: OCEAN PREDATORS

Salmon sharks are a widely roaming species that occupy both coastal and offshore regions throughout the North Pacific. They can reach to over 10 feet in length and exhibit the characteristic "countershading" coloration of many ocean predators, with darker dorsal (back) sides and a light underbelly. This coloration is thought to be at least partly for camouflage while hunting, as the sharks blend in with the dark water when seen from above, and with the light surface when seen from below. In fact, because of their visual similarity to a more famous but significantly larger shark species (think *Jaws*, and white sharks that can reach lengths up to 20 feet), I often refer to salmon sharks as "fun-sized white sharks."

This moniker is appropriate in more ways than one. Closely related to white sharks, salmon sharks exhibit many of the same traits. They are highly efficient top predators, aided by specific physiological features that help them keep their body temperature above that of the surrounding water (a biological process known as "regional endothermy"). Their ability to stay warm in cooler environments provides an important advantage while hunting, particularly when their prey are cold-blooded fishes that might not be able to move as quickly or efficiently. It also means that salmon sharks have a high metabolism, similar to that of marine mammals, and require many calories to make up for the energy they expend.

Because of this, salmon sharks likely have a substantial impact on the populations of prey they consume. However, despite their name, the degree to which salmon sharks specialize on species like Pacific salmon and potentially contribute to their population declines is still unclear. That was the basis for my research questions starting in 2021: what are salmon sharks eating along our coastline, and how much of their diet actually is salmon?

DIVING INTO SALMON SHARK DIET

There are generally two traditional approaches for studying diet in fishes like sharks, and they vary depending on what samples are available for study. The first is stomach content analysis (SCA), which is conducted by flushing the stomach with seawater (for a live animal), or dissecting the stomach of a dead shark and examining what is inside. Depending on when the prey was eaten, it can be very hard to identify the remains. Fortunately, there are parts of most species that do not digest very well; specifically, the inner ear bones of fish (known as otoliths) and the beaks of squid and octopuses. All of these are shaped differently depending on the species, so we can catalog the number and type of prey items in each stomach.

A major limitation of SCA, however, is that it can offer only a recent snapshot into what the animal has just eaten. To address this, we complement SCA with a chemical analysis of shark tissues (called stable isotope analysis, or SIA). Animal tissue like muscle and liver contain a mix of isotopes that

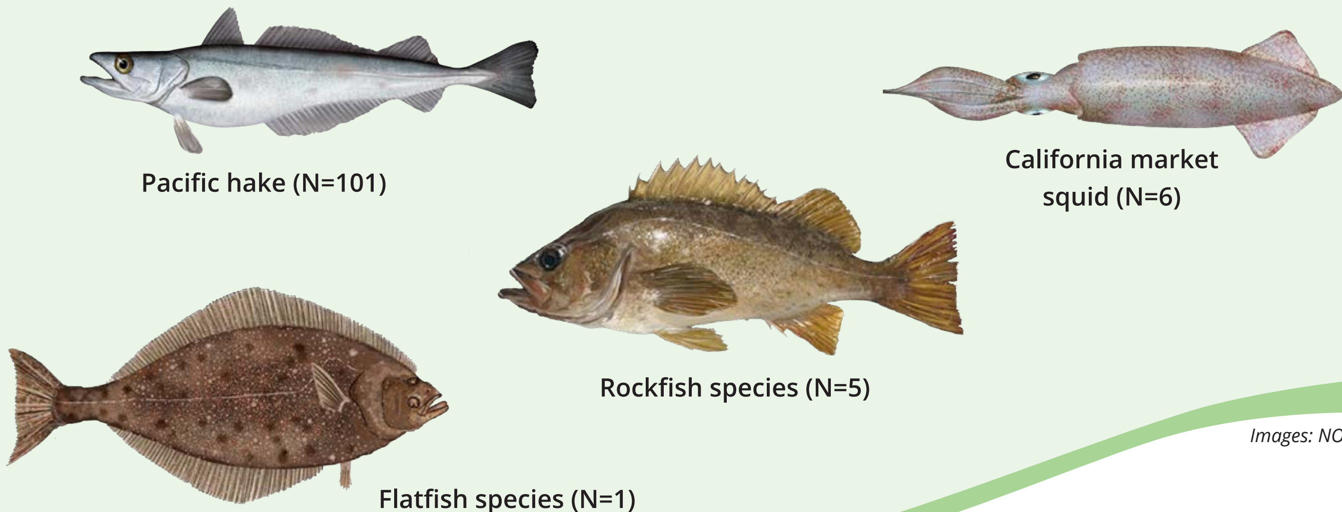
—continued on the next page

> *"We undertook a massive collaborative effort to employ both stomach content analysis and stable isotope analysis to assess salmon shark diet in the California Current Ecosystem, ranging from southern California to Washington."*

Images below, from left to right, depict a whole stomach and spiral valve removed from a salmon shark captured off the coast of Oregon; the author removing a thawed salmon shark stomach from a bucket in preparation for stomach content analysis; the contents of a salmon shark stomach, including otoliths, squid beaks, and unidentified bones, many of which are viewed under a microscope for species identification; and cleaned otoliths removed from a salmon shark stomach, which have been identified to the species and paired to quantify the number of prey items in the stomach (each pair corresponds to one bony fish).

Photos: Alexandra McInturf, Big Fish Lab, Oregon State University



Images: NOAA Fisheries

Prey items identified in the stomach content analysis of salmon sharks in this study ("N" indicates the number of each item). Not pictured: Pacific tomcod (N=3), Rüppell's octopus squid (N=2), and unidentifiable prey items (N=181).

reflects the chemical makeup of both the animal's diet and its habitat (coastal versus offshore waters). Each tissue accumulates this information for different amounts of time, from several months to a year. So by examining multiple tissues of a given predator, we can use SIA to get an idea not only of what prey the animal has been eating over different time periods, but also where it has been going.

In our study, we undertook a massive collaborative effort to employ both SCA and SIA to assess salmon shark diet in the California Current Ecosystem, ranging from southern California to Washington. We obtained whole stomachs and tissue samples from a partnership with the NOAA At-Sea Hake Observer Program, as well as from stranded juvenile salmon sharks found along the Oregon coast. Additional tissue samples were provided by the Washington Department of Fish and Wildlife and Dr. Aaron Carlisle at the University of Delaware. In total, our study included 27 stomachs and tissues from 66 sharks, sampled between 2007–2023. Importantly, these data also allowed us to examine diet differences by sex (male, female) and age class (young-of-year, or one-year old; juvenile, adult). This was the first research project to conduct such a comparison for salmon sharks.

IMPORTANT CONCLUSIONS

We were able to draw several important conclusions from these analyses. To address my original question about the importance of salmon in salmon shark diet, there was no evidence of Pacific salmon in any of the stomachs, but SIA did reveal that younger age groups and adult females had likely preyed upon salmon at some point over the previous year. Yet we did not find any salmon sharks that seemed to specialize in eating salmon, contrary to what might be expected based on their name. Rather, these predators generally consumed a variety of fish and squid.

We also found some variation in diet based on shark sex or age class, which likely reflected the different energetic priorities of each life stage; for instance, growth in younger individuals, or migration and reproduction in adult females. Thus, though salmon sharks may impact different prey populations in specific places or during certain seasons, their overall feeding behaviors do not seem to solely impact one species, salmon or otherwise.

CONSERVATION IMPLICATIONS

However, this information did have broad conservation implications for the predators themselves. Our results showed that regardless of age or sex, the salmon sharks in our study had been foraging recently in the California Current Ecosystem, making this a valuable habitat for the species and potentially one of the only locations where salmon sharks of all life stages overlap. Additionally, many of the prey items we identified in salmon shark diet, such as Pacific hake, California market squid, and various salmon, are commercially valuable in this region. This may put salmon sharks in conflict with commercial fisheries (which has already been reported in previous studies), making information about their diet, movement, and population important parts of ecosystem-based fishery management decisions.

Relatedly, because of their differences in diet, salmon sharks of specific ages or sex might be disproportionately susceptible to accidental capture by commercial fishing operations. For example, most of our samples were from females, which means that the reproducing members of this predator population might be at particular risk to human activity. Removing such individuals in large numbers would dramatically affect the growth of the salmon shark population in our Pacific Northwest region.

> “ *We did not find any salmon sharks that seemed to specialize in eating salmon, contrary to what might be expected based on their name. Rather, these predators generally consumed a variety of fish and squid.* ”

There is also the question of climate change, which is thought to affect the distribution of many fish species. Will the salmon sharks adjust their movement patterns also, or can they simply switch their prey? In general, this study provided some key insights into the effect of these predators in our local waters; however, it also highlighted just how much we still have to learn about this enigmatic species. ▪

*For a deeper dive into this topic, please see the recently published research paper: McInturf, A.G., Teixeira, C.R., Boyt, R. et al. Ontogenetic and sex variation in the foraging ecology of the salmon shark (*Lamna ditropis*) in the California Current ecosystem. Marine Biology 172, 47 (2025). https://doi.org/10.1007/s00227-025-04602-x*

Professional Development

Photos: Courtesy of Skyla Walcott and Burlyn Birkemeier

Above: Skyla Wolcott and Burlyn Birkemeier at conference; Burlyn Berkemeier presenting.

—by Skyla Walcott

Burlyn Birkemeier, Molly McCormley, and I had an amazing time at the Society for Marine Mammalogy Conference in Perth, Australia. We were able to see a wide variety of scientific talks, and were inspired by the way the conference directors kept indigenous knowledge and experiences at the forefront of the conference plenaries and conversations. We're definitely very grateful that the Professional Development Program exists and allowed us to travel to Australia for the incredible experience!

Funding and Initiatives

Photo: gaiamoments at iStockphoto.com

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 in 1977 to foster collaborative research between the National Oceanic and Atmospheric Administration (NOAA) and the University of Washington (UW). In 2020, this unique 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), and 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 to advance scientific knowledge about the planet's climate, oceans, and ecosystems. Through collaborative efforts, the integrated team of CICOES researchers and affiliates strengthen and extend their areas of research and 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 research 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 restore and protect marine habitats.
- Improving tsunami forecasting and prediction of impacts.
- And much more: cicoes.uw.edu/research/

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 our internal Initiatives, including the:

- Postdoctoral scholar program
- Graduate student fellowships
- Research development grants
- Professional development program
- Employee engagement program
- 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.

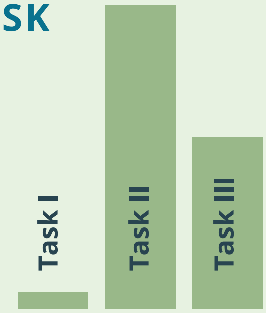
TASK III supports research related to CICOES' themes on the UW, OSU, or UAF campuses, and includes a broad range of departments. Principal Investigators include university academic and research faculty, as well as research scientists.

$15,252,191 TOTAL COOPERATIVE INSTITUTE FUNDING

BY CONSORTIUM PARTNERS

UW	$13,834,222
UAF	$1,417,969
OSU	$0

BY TASK



Task I: $400,983

Task II: $9,538,353

Task III: $5,312,855

BY THEME

Climate and Ocean Variability, Change and Impacts	$688,564
Earth Systems and Processes	$1,491,311
Environmental Chemistry and Ocean Carbon	$3,175,237
Environmental Data Science	$831,478
Marine Ecosystems: Observation, Analysis, and Forecasts	$2,348,226
Multiple	$1,016,240
Ocean and Coastal Observations	$5,361,415
Polar Studies	$339,720

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). Historically the total external funding has averaged between $2M and $4M annually.

TASK V includes NOAA funding under the two federal initiatives listed below.

- Inflation Reduction Act
- Bipartisan Infrastructure Law

In 2024 CICOES was awarded $11,547,947 in Task V funds, the majority of which went to partner departments at UW.

INITIATIVES

Funded primarily by Task I, CICOES supports seven internal initiative programs:

Summer Internship Program

The CICOES internship program, funded primarily by an NSF REU grant, offers nine-week research opportunities for 14 undergraduate students. Interns are matched with a research project and work with a CICOES, NOAA, or University of Washington mentor at either the UW campus or the NOAA Western Regional Center in Seattle.

Postdoctoral Scholars Program

Since 1977, CICOES has committed a significant share of its initiative budget to annually support up to three 2-year postdoctoral research scholars. The program has been highly successful; 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.

Graduate Student Fellowships

The graduate student award program was initiated in 2019. The program awards up to 6 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

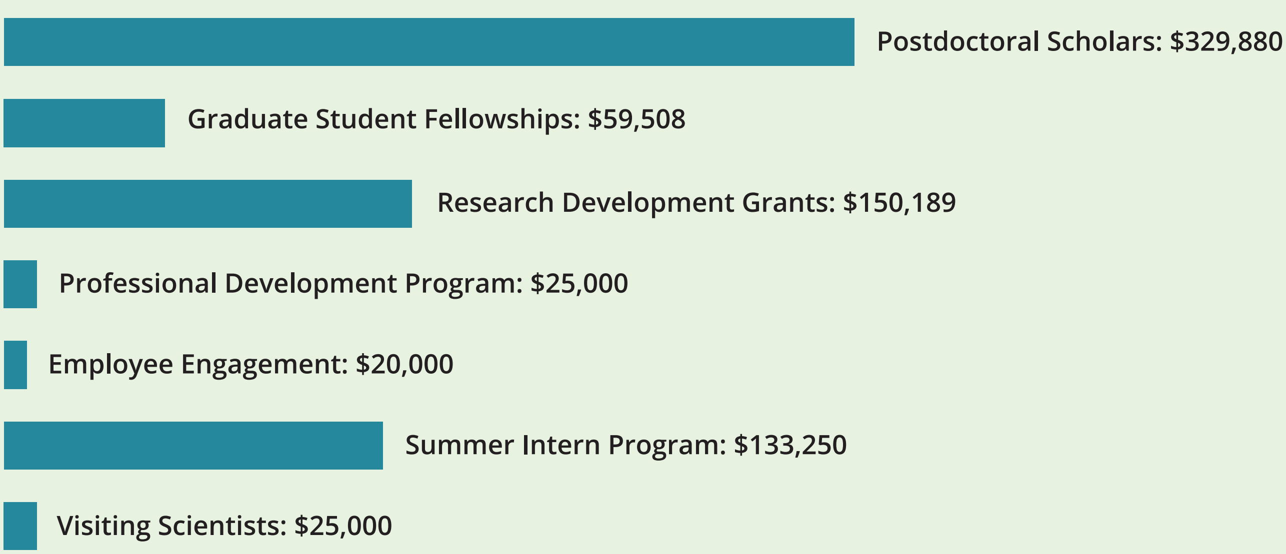
Since 2015, CICOES has allocated an average of $120K per year to stimulate new, innovative research.

Professional Development Program

First piloted in 2019 and now an ongoing program, the CICOES professional development program allocates $25K per year for employees to use toward professional development opportunities. See examples featured on pages 25 and 29.

$742,827 CICOES INITIATIVES

CICOES initiatives are funded by Task I funding, NSF, and internal UW support.



Employee Engagement

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. $20k of internal UW funds per year are allocated to support this work.

Visiting Scientist Program

The Visiting Scientist Program, funded at approximately $25K per year, 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. ▪

CICOES FUNDING TO OTHER UW DEPARTMENTS

APL	Applied Physics Lab	$234,680
W	Atmospheric & Climate Sciences	$238,353
W	EarthLab	$145,870
	Oceanography	$2,911,742
SAFS	Aquatic & Fishery Sciences	$663,774

Professional Development

Photo: Isa van der Knijf

—by Carol Pérez / CICOES

Dana Wright, a research scientist at the AFSC Marine Mammal Laboratory, used funds from the Professional Development program to attend the 2024 Detection, Classification, Localization, and Density Estimation (DCLDE) workshop in Rotterdam, the Netherlands. This five-day event brought together scientists from across the globe who are advancing machine learning techniques for analyzing bioacoustics data to estimate marine mammal populations.

"I am so grateful to have been able to attend this workshop and learn the latest techniques in my field from leading experts," said Dana.

The workshop offered a unique structure, beginning with a day of hands-on training, followed by four days of presentations and dedicated discussion periods. These open-discussion sessions provided valuable time for participants to collaborate, brainstorm solutions, and tackle some of the field's most complex challenges.

"This workshop felt like a close-knit group of scientists who have been working through complex problems for many years. Being part of these discussions and learning from such experienced colleagues was incredibly valuable for my career. I'm also excited about the potential for new international collaborations that could come from this experience."

Learning from eco-grief and climate anxiety

Photo: Courtesy of McKenna Sweet

—by McKenna Sweet (UW)

The most chaotically enriching 48 hours of my life started with feeling overwhelmed by climate change and an article.

CLIMATE CRISIS ANXIETY

In May of 2023, the climate crisis was weighing particularly heavily on me. This feeling wasn't new to me as a conservation biology major—especially since I usually cry during any lectures where we learn more about climate change.

But after sitting with this feeling for a while, I thought to myself: if I'm feeling this way, then how are the people who have been studying climate change longer than I've been alive feeling?

With my other major being journalism, I set out to answer this question by interviewing four climate and environmental researchers and writing an article for UW's student newspaper, *The Daily*, about their experiences with climate anxiety. I felt honored that these people felt comfortable enough to be vulnerable with me, and I received many thanks for writing what is now one of my favorite articles out of the 50-plus I've written.

Then, that August, I got a LinkedIn message from CICOES/PMEL research coordinator Heather Tabisola encouraging me to submit an abstract based on the content from my article for her session at the Ocean Sciences Meeting (OSM) titled "Showing Up and Sharing Science: Varying Approaches in Building Capacity and Communicating Science in the Climate Crisis."

My brain immediately convinced me that I was unqualified to do this for plenty of reasons: I knew nothing about marine biology, I had never attended—let alone spoken at—a conference, and I wasn't even old enough to buy a hotel room for the conference.

But I submitted my abstract, was accepted to speak at the conference, and stumbled successfully through booking accommodation and a flight to New Orleans for the OSM in February 2024.

After leaving Seattle on a Monday night after classes, I arrived in New Orleans close to midnight, starting the clock for the next 39 hours in the city. The first and longest leg of this schedule was on that Tuesday, which was the day I would actually step forward and present at my first conference.

PRESENTATION & AUDIENCE RESPONSE

My presentation that afternoon, "The Sea of Grief and Hope Around Us: How Expressing Climate-Anxiety Can Help Environmental Scientists and the Public Alike," was based on the results of multiple interviews with marine researchers about their climate anxiety and their coping mechanisms. It also discussed how scientists being open about their own emotional experiences could help the public as they maneuver their own climate anxieties by showing that they're not alone in these feelings.

Not only did the audience laugh and cry during my 12-minute talk, but I received so much positive feedback afterward and actually had someone stop me on the street to thank me for a great presentation.

The responses I received after both my article and conference talk solidified my inspiration for both products, which was that talking about climate anxiety among the scientific community needs to happen more to validate what many of us are feeling all the time.

Composite photo: appledesign at iStockphoto.com

As someone getting a double degree in conservation biology and journalism, I'm in the privileged position to understand and share the science behind the climate crisis and bear witness to those who disproportionately experience its effects. While the conference presentation was primarily meant to validate scientists' anxieties, my article was meant to let the public know that they aren't the only ones feeling anxious about the state of our home.

I can't say my climate anxiety has completely dissipated since OSM, but I do feel less alone after talking to dozens of researchers and students about their emotions surrounding the topic. I've also found that this benefit is a two-way street since almost everyone I've interviewed about climate anxiety has thanked me for allowing them to talk about their experiences. This could mean that the public might benefit from either having conversations with scientists about eco-anxiety or from merely hearing scientists be more open about their experiences with this emotion.

Although I'm slowly becoming a scientist, I'm still a member of the public who is affected emotionally by climate change. I vividly remember a professor from a conservation biology course saying, "we will lose species despite our best efforts," which made me tear up during class. As someone who got into conservation to save species, I can't help but feel an immense wave of grief when I think about how this is an unfortunate truth.

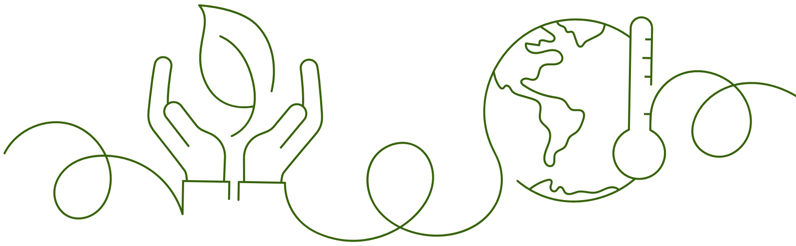
I let this grief linger instead of trying to suppress it, though, which is admittedly a difficult thing to do and has taken practice. Grief isn't comfortable, but it is so powerful when prevented from cementing into apathy. My love for the flora and fauna on this planet is naturally accompanied by my preemptive grief for them, which keeps me motivated to study them and tell their stories, in hopes that someone will eventually listen.

PEOPLE ARE LISTENING

And plenty of people are listening. Conservation biology has taught me who has been studying the climate crisis and its solutions longer than I've been alive, and journalism has allowed me to talk with them and share their stories. Combined, my two degrees (and unwavering support from Heather Tabisola) allowed me to talk to a conference room of people from multiple disciplines who needed the reassurance that they were not alone in their feelings of climate anxiety and grief.

I ended my presentation with a quote allegedly from the 16th-century astronomer Tycho Brahe, which read: "I admit that I was trying to find out the meaning of the universe, and I haven't found it yet. But I believe that someday, somebody will. And I will have saved that person 25 years of labor."

Just as I refuse to see my grief devolve into apathy, the environmental work that I am committed to accomplishing throughout my evolving career will not go to waste. So, thank you to those before me, and I look forward to providing my labor across the next 25 years to help save our home. ■

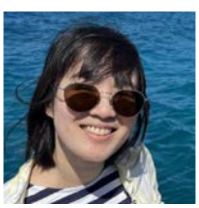


GET TO KNOW

Our New Employees

Please welcome these 13 individuals who joined the CICOES-UW staff between December 2023 and November 2024.

Varunesh Chandra is a post-doctoral researcher who earned a PhD in Atmospheric Science from the Indian Institute of Technology (Delhi, India) in 2023. Varunesh is working with CICOES researcher Muyin Wang, PMEL's James Overland, and UW's Qiang Fu to investigate the causes and consequences of Arctic Amplification, specifically examining how melting Arctic sea ice influences mid-latitude regions. This project focuses on the connection between the recent decline in winter Arctic sea ice and cold weather extremes in the mid-latitude areas, particularly potential vorticity dynamics—investigating how the weakening of the meridional potential vorticity barrier interacts with cold extremes across various regions and different time scales, using observational data, model outputs (e.g., CMIPs and Large Ensemble Runs), and experimental support through climate modeling.



Nan-Hsun Chi is a research scientist at PMEL. Her research experience includes air-sea interactions and small-scale processes in the upper ocean, and their impacts on the upper ocean heat, salinity, and momentum budgets both in the tropics and in the Arctic. She participated in two research cruises, one in the South China Sea and one in the central Indian Ocean, and has supported mission management during Saildrone hurricane missions since 2022.

Camille Hankel is a postdoctoral researcher who earned her PhD in Earth and Planetary Sciences from Harvard University in 2024. Camille is working with Cecilia Bitz at UW and Wei Cheng at PMEL on how the Atlantic Meridional Overturning Circulation is sensitive to the rate of CO_2 change in global climate models. By isolating the impact of the rate of CO_2 change from the magnitude of CO_2, she explores new coupled climate feedbacks that emerge due to nonlinear interactions between the different response timescales of the ocean, sea ice, and atmosphere. She also studies other large-scale climate phenomena that may exhibit abrupt responses to CO_2 or sensitivity to the rate of CO_2 change, with a particular interest in those that impact the high latitudes. In her free time, Camille loves playing tennis, hiking, and foraging for mushrooms.

Rui Jin is a postdoctoral researcher who earned her PhD in Earth and Planetary Sciences from Johns Hopkins University in 2024. Rui specializes in coastal and Earth system model development, focusing on the dynamics of biogeochemical processes within ocean ecosystems. She collaborates with CICOES scientist Albert Hermann and NOAA researchers Kelly Kearney, Brendan Carter, and Darren Pilcher to investigate marine carbon dioxide removal (mCDR) through computational modeling. Rui's research leverages the global MOM6-COBALT Earth system model to explore how biotic calcification feedbacks affect the effectiveness of mCDR strategies on century-scale timescales. By advancing understanding of these feedbacks, Rui aims to help optimize mCDR approaches that could reduce atmospheric CO_2 and mitigate climate change. Her work, which involves refining biogeochemical model variants and evaluating results against observational data, will contribute to broader efforts to assess mCDR potential and guide future interventions in ocean-based carbon management.

Choong Kim is the new Grants Manager for CICOES. Choong's main focus is related to the Cooperative Agreement Award, and he also works on grant proposals, subawards, budget setups, and compliance issues. Before joining CICOES he spent time at Computer Science and Engineering, the College of Education, and the School of Law. Choong graduated from the University of Washington, majoring in Geography and Anthropology. His free time is spent with his family and their family dog.

Gulce Kurtay is a marine biologist with a focus on phytoplankton ecology and aquatic microbial interactions. She earned her PhD in Environmental and Evolutionary Biology from the University of Louisiana at Lafayette, and an MSc in Marine Environment and Resources through the Erasmus Mundus program in Europe (UK, Spain, Belgium). Currently, she works with CICOES scientists Calvin Mordy and Jens Nielsen, utilizing machine learning and AI techniques to develop classification models for identifying phytoplankton taxa. Her work emphasizes characterizing phytoplankton traits from microscopic images collected on EcoFOCI research cruises in the Gulf of Alaska and in the Bering and Chukchi seas.

Edoardo Mazza is a research scientist at CICOES who earned his PhD in Atmospheric Sciences at the University of Washington and his BSc with Honors in Geophysics and Meteorology at the University of Edinburgh. Prior to joining CICOES, he was an NRC postdoc at the NOAA PMEL. Edoardo is working with CICOES' Andy Chiodi and PMEL's Chidong Zhang. His research focuses on advancing our understanding of extreme events across the weather-climate continuum. He employs a diverse set of tools, from cutting-edge in-situ observations to fully coupled numerical simulations, with the ultimate goal of improving our preparedness and resilience. Edoardo's primary project explores the virtual navigation of uncrewed systems (UxS) within high-resolution, fully coupled simulations to design co-located UxS measurements within the tropical Air-Sea Transition Zone.

Elizabeth McGeorge is a postdoctoral researcher who earned her PhD in Mathematics from the University of Canterbury in 2023. She is working with Dr. Yolande Serra (CICOES), Dr. Dongxiao Zhang (CICOES/PMEL) and Dr. Meghan Cronin (PMEL). Her PhD thesis was in the field of computational fluid dynamics and explored inverse problems methods, such as optimal control, for geophysical fluid flows. She enjoys using mathematical modeling and computational methods to analyze complex environmental phenomena. Her current research utilizes Unmanned Surface Vehicles (USVs) to observe the eastern edge of the warm pool and estimate upwelling in the tropical Pacific region with the goal of contributing to the advancement of our understanding of the processes in the tropical Pacific and the needs of observational systems. In her spare time, she enjoys sailing big and small boats.

Stephanie (Steffi) O'Daly is a postdoctoral researcher who earned her PhD in Chemical Oceanography at the University of Alaska Fairbanks in 2024. Steffi is working with Zachary Erickson at PMEL and Adam Martiny at UC Irvine to study drivers of carbon export in the global oceans using an Underwater Vision Profiler (UVP) with the GO-SHIP and Bio GO-SHIP programs. Carbon is fixed by phytoplankton and can sink into the deep sea, where it is sequestered from the atmosphere through the natural process called the Biological Carbon Pump (BCP). The goal of this project is to identify drivers of the BCP to improve models of global carbon export in the ocean.

Yakelyn Ramos Jauregui, originally from Peru, studied meteorology at the Universidad Nacional La Agraria La Molina and has worked at the Peruvian Geophysical Institute, providing scientific support for El Niño-Southern Oscillation (ENSO) predictions. She earned her PhD in Atmospheric Sciences from the University of Washington in 2024, where her research focused on understanding the interactions between the Madden-Julian Oscillation and El Niño onset, particularly the effects of large-scale freshwater fluxes on ocean currents. Currently, she is a postdoctoral researcher at NOAA's Climate-Weather Interface group working under the mentorship of Dr. Chidong Zhang. During her postdoctoral research, she is collaborating with JPL scientists to enhance atmospheric river (AR) prediction capabilities by integrating GPS retrievals with satellites and Numerical Weather Prediction (NWP) datasets to reduce NWP's biases associated with ARs. Her main goal is to develop software solutions for optimal buoy placement to gather real-time AR precipitable water vapor data, improving predictive capabilities in areas prone to AR. In addition, she is contributing to the planning of the upcoming Tropical Pacific Observing Experiment (TPEX) international field campaign scheduled for 2026–2027.

Sharae Saleem is the Payroll Coordinator for CICOES. Before joining CICOES, Sharae was the Payroll Analyst 2 for Washington State Patrol. She holds a Bachelor's degree in Family Studies from Lamar University in Beaumont, Texas. Outside of being an active member of her local community-conscious and action-oriented sorority, Zeta Phi Beta Sorority Inc., she enjoys listening to great music and reading a good book.

Jim Schloemer is part of the Global Tropical Moored Buoy Array program at NOAA PMEL. He works in the lab and on the water to build, repair, and install deep-ocean mooring systems that inform many of the global oceanographic and climate models. Prior to joining CICOES in January, he received an MS in Marine Biology from the University of Alaska Fairbanks and spent a decade working in the Gulf of Alaska and Arctic Ocean. In general, he is interested in the long-term monitoring of ecosystem drivers, how the physical ocean structures ecosystems through bottom-up control, and the connections between terrestrial landscapes and coastal systems. Jim is excited to support aquatic science in any capacity.

Sam Setta is a postdoctoral researcher who earned her MS in Marine Biology from Texas A&M University and a PhD in Oceanography from The University of Rhode Island's Graduate School of Oceanography in 2023. Sam is working with CICOES researcher Sean McAllister and PMEL's Zachary Gold in the Ocean Molecular Ecology group at the Pacific Marine Environmental Lab to study the impacts of a changing environment on phytoplankton. Using environmental DNA from the West Coast Ocean Acidification Cruise in 2021, Sam will determine best practices for assigning taxonomy to DNA meta-barcoding results. Applying these methods, Sam will investigate the distribution and occurrence of phytoplankton across the U.S. West Coast, Alaska, and the Arctic to determine how changes in temperature, nutrients, and ocean acidification affect these important primary producers at the base of the food web. ▪

Publications

Photo: sharply_done at iStockphoto.com

CICOES researchers authored or co-authored the following publications between November 2023 and October 2024. Names in bold indicate CICOES-affiliated authors. Listings preceded by an asterisk denote publications of work that was supported via CICOES funding but without a CICOES-affiliated author.

Aliaga, B, M Angove, R Bailey, S Chacon, CV Hillebrandt-Andrade, BM Howe, S Kumar, HP Rahayu, **Y Wei** (2024), Trends and impacts of warning systems for ocean-related hazards, Outcome vs. Status, UNESCO State of the Ocean report 2024, 59-62, doi:10.25607/4wbg-d349.

Alin, S, J Newton, D Greeley, B Curry, **J Herndon**, A Kozyr, RA Feely (2023), A multi-stressor data product for marine heatwave, hypoxia, and ocean acidification research, including calculated inorganic carbon parameters from the southern Salish Sea and northern California Current System from 2008-02-04 to 2018-10-19, NOAA Data Catalog, NCEI Accession 0283266, doi:https://catalog.data.gov/dataset/a-multi-stressor-data-product-for-marine- heatwave-hypoxia-and-ocean-acidification-research-incl.

Alin, S, S Siedlecki, H Berger, R Feely, J Waddell, **B Carter**, J Newton, E Schumacker, and D Ayres (2023), Evaluating the evolving ocean acidification risk to Dungeness Crab: time-series observations and modeling on the Olympic Coast, Washington, USA, Oceanography, 36(2-3), doi:10.5670/oceanog.2023.216.

Alin, SR, JA Newton, RA Feely, D Greeley, B Curry, **J Herndon**, and M Warner (2023), A decade-long cruise time-series (2008–2018) of physical and biogeochemical conditions in the southern Salish Sea, North America, Earth System Science Data Discussion, 2023, 1-37, doi:10.5194/essd-2023-239.

*Alkire, MB, and S Riser (2023), Net community production in the Argentine Basin estimated from nitrate drawdown using biogeochemical Argo Floats, Journal of Geophysical Research: Oceans, 128(8), doi:10.1029/2023JC019858.

Annasawmy, P, **JK Horne**, CS Reiss, and GJ Macaulay (2023), Characterizing Antarctic air-breathing predator dive patterns on a common prey base from stationary echosounders, Polar Science, 39, doi:10.1016/j.polar.2023.100974.

Axler, KE, ED Goldstein**, JM Nielsen**, AL Deary, and JT Duffy-Anderson (2023), Shifts in the composition and distribution of Pacific Arctic larval fish assemblages in response to rapid ecosystem change, Global Change Biology, 29(15), 4212-4233, doi:10.1111/gcb.16721.

Barlow, DR, H Klinck, D Ponirakis, **TA Branch**, and LG Torres (2023), Environmental conditions and marine heatwaves influence blue whale foraging and reproductive effort, Ecology and Evolution, 13(2), doi:10.1002/ece3.9770.

*Barry, PD, CM Kondzela, JA Whittle, JT Watson, K Karpan, K D'Amelio, and WA Larson (2022), Genetic stock composition analysis of chum salmon from the prohibited species catch of the 2020 Bering Sea walleye pollock trawl fishery, NOAA technical memorandum NMFS-AFSC; 453, doi:10.25923/je03-2052. (UAF person)

Barth, JA, SD Pierce, **BR Carter**, F Chan, AY Erofeev, JL Fisher, RA Feely, KC Jacobson, AA Keller, CA Morgan, JE Pohl, LK Rasmuson, V Simon (2024), Widespread and increasing near-bottom hypoxia in the coastal ocean off the United States Pacific Northwest, Scientific reports, 14(1), 3798, doi:10.1038/s41598-024-54476-0.

Berger, AM, C Barcelo, DR Goethal, SD Hoyle, P Lynch, J McKenzie, A Dunn, **AE Punt**, RD Methot, J Hampton, C Porch, R McGarvey, J Thorson, T A'mar, J Deroba, BP Elvarsson, SJ Holmes, D Howelll, BJ Langesth, C March, MN Maunder, S Mormede, S Rasmusson

(2024), Synthesizing the spatial functionality of contemporary stock assessment software to identify future needs for next generation assessment platforms, Fishery Research, Volume 275: 107008, ISSN 0165-7836, doi:10.1016/j. fishres.2024.107008.

Bernard, E, C Meinig, VV Titov, **Y Wei** (2023), 50 years of PMEL tsunami research and development, Oceanography, 36(2-3), 175-185, doi:10.5670/oceanog. 2023.208.

*Blackburn, DC, DM Boyer, JA Gray, J Winchester, JM Bates, SL Baumgart, E Braker, D Coldren, KW Conway, A Davis Rabosky, N de la Sancha, CB Dillman, JL Dunnum, CM Early, BW Frable, MW Gage, J Hanken, JA Maisano, BD Marks, KP Maslenikov, JE McCormack, RS Nagesan, GG Pandelis, HL Prestridge, DL Rabosky, ZS Randall, MB Robbins, LA Scheinberg, CL Spencer, AP Summers, L Tapanila, CW Thompson, L Tornabene et al., (2024), Increasing the impact of vertebrate scientific collections through 3D imaging: The openVertebrate (oVert) Thematic Collections Network, BioScience, 74(3), 169-186, doi:10.1093/biosci/ biad120.

Bortolotto, GA, **AN Zerbini**, L Thomas, A Andriolo, PS Hammond (2023), Distribution and habitat use modelling from satellite tracking data of humpback whales in Brazil agrees with shipboard survey data modelling, Marine Ecology Progress Series, 720: 161-74, doi:org/10.3354/meps14404.

Bourbonnais, A, **BX Chang**, **RE Sonnerup**, SC Doney, and MA Altabet (2023), Marine N_2O cycling from high spatial resolution concentration, stable isotopic and isotopomer measurements along a meridional transect in the eastern Pacific Ocean, Frontiers in Marine Science, 10, doi:10.3389/fmars.2023.1137064.

Photo: Jessica M. Lindsay/NOAA Fisheries

A closeup of a white-coated ribbon seal pup (*Histriophoca fasciata*) on an ice floe.

Photo taken while working under authority of NMFS Research Permit #23858.

*Branch, TA, IM Coté, SR David, JA Drew, M LaRue, MC Márquez, ECM Parsons, D Rabaiotti, D Shiffman, DA Steen, AL Wild (2024), Controlled experiment finds no detectable citation bump from Twitter promotion, PloS one, 19(3), doi:10.1371/journal.pone.0292201.

Brewer, AM, **M Castellote**, AM Van Cise, T Gage, AM Berdahl (2023), Communication in Cook Inlet beluga whales: Describing the vocal repertoire and masking of calls by commercial ship noise, The Journal of the Acoustical Society of America, 154 (5): 3487–3505, doi:10.1121/10.0022516.

*Bumbaco, KA, CL Raymond, LW O'Neill, DJ Hoekema (2024), 2023 Pacific Northwest Water Year Impacts Assessment, A collaboration among the Office of the Washington State Climatologist, Climate Impacts Group, Oregon Climate Service, Idaho Department of Water Resources, and NOAA National Integrated Drought Information System, doi:drought.gov/ documents/2023-pacific-northwest-water-year-impacts-assessment.

Burger, EF, **KM O'Brien**, S Hankin, R Schweitzer, **L Kamb**, **S Osborne**, A Manke (2023), Data processing and management at PMEL: a 50-year perspective, Oceanography, 36(2-3), 26-31, doi:10.5670/oceanog. 2023.230.

Butterfield, DA, SL Walker, T Baumberger, J Beeson, **J Resing**, SG Merle, A Antriasian, **K Roe**, G-S Lu, **P Barrett,** WW Chadwick Jr. (2023), The PMEL Earth-Ocean Interactions Program: Beyond vents, Oceanography, 36(2-3), 206-211, doi:10.5670/ oceanog.2023.229.

*Cai, W, B Ng, T Geng, F Jia, L Wu, G Wang, Y Liu, B Gan, K Yang, A Santoso, X Lin, Z Li, Y Liu, Y Yang, F-F Jin, M Collins, and MJ McPhaden (2023), Anthropogenic impacts on twentieth-century ENSO variability changes, Nature Reviews Earth & Environment, 4, 407-418, doi:10.1038/s43017-023-00427-8.

*Capotondi, A, S McGregor, MJ McPhaden, S Cravatte, NJ Holbrook, Y Imada, SC Sanchez, J Sprintall, MF Stuecker, CC Ummenhofer, M Zeller, R Farneti, G Graffino, S Hu, K Karnauskas, Y Kosaka, F Kucharski, M Mayer, B Qiu, A Santoso, AS Taschetto, F Wang, X Zhang, RM Holmes, J Luo, N Maher, C Martinez-Villalobos, GA Meehl, R Naha, N Schneider, S Stevenson, A Sullivan, P van Rensch, T Xu (2023), Mechanisms of tropical Pacific decadal variability. Nature Reviews Earch & Environment, 4, 754–769, doi:10.1038/s43017-023-00486-x.

Carter, BR, **J Sharp**, AG Dickson, M Álvarez, MB Fong, MI García-Ibáñez, RJ Woosley, Y Takeshita, L Barbero, RH Byrne, W Cai, M Chierici, SL Clegg, RA Easley,

AJ Fassbender, KL Fleger, X Li, M Martín-Mayor, KM Schockman, ZA Wang (2024), Uncertainty sources for measurable ocean carbonate chemistry variables, Limnology and Oceanography, 69(1), 1-21, doi:10.1002/lno.12477.

Castellote, M, V Gill, C Garner, A Gilstad, B Hou, **A Brewer**, J Knoth (2023), Using passive acoustics to identify a winter foraging refugia and quiet space for an endangered beluga population in Alaska, Anchorage: US Department of the Interior, Bureau of Ocean Energy Management. 55p. Report No.: OCS Study BOEM 2023-074. Contract No.: M20PG00005.

*Chamberlain, P, B Cornuelle, L Talley, K Speer, C. Hancock, and S Riser, (2023), Acoustic float tracking with the Kalman smoother, Journal of Atmospheric and Oceanic Technology, 40, 15-35, doi:10.1175/JTECH-D-21-0063.1.

Charlton, C, F Christiansen, R Ward, AI Mackay, V Andrews-Goff, **AN Zerbini**, S Childerhouse, S Guggenheimer, B O'Shannessy, RL Brownell, Jr. (2023), Evaluating short- to medium-term effects of implantable satellite tags on southern right whales *Eubalaena australis*, Diseases of Aquatic Organisms, Vol. 155: 125–140, doi:10.3354/dao03730.

Chen, YA, AC Haynie, **CM Anderson** (2023), Full-information selection bias correction for discrete choice models with observation-conditional regressors, Journal of the Association of Environmental and Resource Economists, University of Chicago Press, vol. 10(1), pages 231-261, doi:10.1086/719794.

Chi, N-H, **D Zhang**, C Zhang (2023), Validation of OSCAR Surface currents in the western Arctic marginal seas against saildrone observations, Earth and Space Science, 10(11), doi:10.1029/2022EA002612.

Chiodi, AM, H Hristova, GR Foltz, JA Zhang, **CW Mordy**, CR Edwards, C Zhang, C Meinig, **D Zhan**g, E Mazza, ED Cokelet, EF Burger, F Bringas, G Goni, H-S Kim, S Chen, J Trianes, K Bailey, KM O'Brien, M Morales-Caez, N Lawrence-Slavas, SS Chen, X Chen (2024), Surface ocean warming near the core of hurricane Sam and its representation in forecast models, Frontiers in Marine Science, 10, doi:10.3389/fmars.2023.1297974.

Christman, C, **S Walcott,** J London, E Richmond, S Koslovsky (2024), Aerial surveys of harbor seals (*Phoca vitulina richardii*) in Behm Canal, Alaska: Results from surveys conducted by NOAA, National Marine Fisheries Service in September 2022 and June 2023, NOAA AFSC/MML/CICOES Processed Report 2024-02, doi:10.25923/hf8m-xf16.

Christman, CL, **SM Walcott**, JM London, EL Richmond, SM Koslovsky (2023), Aerial surveys of harbor seals (*Phoca vitulina richardii*) in Iliamna Lake, Alaska, NOAA AFSC/MML/CICOES Processed Report 2023-06, doi:10.25923/rcqf-9v27.

Chylek, P, CK Folland, JD Klett, **M Wang**, G Lesins, MK Dubey (2023), High values of the Arctic Amplification in the early decades of the 21st century: Causes of discrepancy by CMIP6 models between observation and simulation, JGR Atmospheres, Vol 128, Issue 23, doi:10.1029/2023JD039269.

Connell, KJ, **MJ McPhaden**, GR Foltz, RC Perez, K Grissom, (2023), Surviving piracy and the coronavirus pandemic, Oceanography, 36(2–3):44–45, doi:10.5670/oceanog.2023.212.

Correa, GM, CC Monnahan, JY Sullivan, JT Thorson, **AE Punt** (2023), Modelling time-varying growth in state-space stock assessments, ICES Journal of Marine Science, 80(7), 2036-2049, doi:10.1093/icesjms/fsad133.

Cronin, MF, ND Anderson, **D Zhang**, **P Berk**, **SM Wills**, **Y Serra**, C Kohlman, AJ Sutton, MC Honda, Y Kawai, J Yang, J Thomson, N Lawrence-Slavas, **J Reeves Eyre,** C Meinig (2023), PMEL Ocean climate stations as reference time series and research aggregate devices, Oceanography, 36(2-3), 46-53, doi:10.5670/oceanog.2023.224.

Cronin, MF, **D Zhang**, **SM Wills**, **JEJ Reeves Eyre**, L Thompson, **N Anderson** (2024), Diurnal warming rectification in the tropical Pacific linked to sea surface temperature front, Nature Geoscience, doi:10.1038/s41561-024-01391-8.

Cross, JN, C Sweeney, EB Jewett, RA Feely, P McElhany, **BR Carter**, T Stein, GD Kitch, DK Gledhill (2023), Strategy for NOAA Carbon Dioxide Removal Research: A white paper documenting a potential NOAA CDR Science Strategy as an element of NOAA's Climate Interventions Portfolio., NOAA Special Report. NOAA, Washington DC, doi:10.25923/gzke-8730.

DeVries, T, K Yamamoto, R Wanninkhof, N Gruber, I Hauck, JD Müller, L Bopp, D Carroll, **BR Carter**, C Thi-Tuyet-Trang Chau, SC Doney, M Gehlen, L Gloege, L Gregor, S Henson, JH Kim, Y Iida, T Ilyina, P Landschützer, C Le Quéré, D Munro, C Nissen, L Patara, FF Pérez, L Resplandy, KB Rodgers, J Schwinger, R Séférian, V Sicardi, J Terhaar, J Triñanes, H Tsujino, A Watson, S Yasunaka, J Zeng (2023), Magnitude, trends, and variability of the global ocean carbon sink from 1985 to 2018, Global Biogeochemical Cycles, 37(10), doi:10.1029/2023GB007780.

*Dias, BS, DW McGowan, R Campbell, TA Branch (2022), Influence of environmental and population factors on Prince William Sound herring spawning phenology, Marine Ecology Progress Series, 696, 103-117, doi:10.3354/meps14133.

Eastman, R, IL McCoy, H Schulz, **R Wood** (2023), A survey of radiative and physical properties of North Atlantic mesoscale cloud morphologies from multiple identification methodologies, EGUsphere, 2023, 1-33, doi:10.5194/egusphere-2023-2118.

Erickson, ZK, **BR Carter**, RA Feely, GC Johnson, **JD Sharp**, **RE Sonnerup** (2023), PMEL's Contribution to observing and analyzing decadal global ocean changes through sustained repeat hydrography, Oceanography, 36(2-3), 60-69, doi:10.5670/oceanog.2023.204.

Fassbender, AJ, **BR Carter**, **JD Sharp**, Y Huang, MC Arroyo, and **H Frenzel** (2023), Amplified subsurface signals of ocean acidification, global biogeochemical cycles, 37(12), doi:10.1029/2023GB007843.

*Fay, AR, DR Munro, GA McKinley, D Pierrot, SC Sutherland, C Sweeney, R Wanninkhof (2023), Updated climatological mean delta fCO2 and net sea-air CO2 flux over the global open ocean regions, Earth System Science Data Discussions, 1–35, doi:10.5194/essd-2023-429.

Feddern, M, **J Nielsen**, T Essington, G Holtgrieve (2023), The influence of dynamic resources and stable isotope incorporation rates on aquatic consumer trophic position estimation, Limnology and Oceanography: Methods, doi:10.1002/lom3.10595.

Feely, RA, L-Q Jiang, R Wanninkhof, **BR Carter**, SR Alin, N Bednaršek, CE Cosca (2023), Acidification of the global surface ocean: What we have learned from observations, Oceanography, 36(2-3), 120-129, doi:10.5670/oceanog.2023.222.

Fennel, K, MC Long, C Algar, **BR Carter**, D Keller, A Laurent, JP Mattern, R Musgrave, A Oschlies, J Ostiguy, JB Palter, DB Whitt (2023), Modelling considerations for research on ocean alkalinity enhancement (OAE), State Planet: Guide to Best Practices in Ocean Alkalinity Enhancement Research, 9, doi:10.5194/sp-2-oae2023-9-2023.

*Friedlingstein, P, M O'Sullivan, MW Jones, RM Andrew, DCE Bakker, J Hauck, P Landschützer, C Le Quéré, IT Luijkx, GP Peters, W Peters, J Pongratz, C Schwingshackl, S Sitch, JG Canadell, P Ciais, RB Jackson, SR Alin, P Anthoni, L Barbero, NR Bates, M Becker, N Bellouin, B Decharme, L Bopp, IBM Brasika, P.Cadule, MA Chamberlain, N Chandra, T-T-T Chau, et al. (2023), Global Carbon Budget 2023, Earth Syst. Sci. Data, 15(12), 5301-5369, doi:10.5194/essd-15-5301-2023.

Fullerton, H, L Smith, A Enriquez, **D Butterfield**, CG Wheat, CL Moyer (2024), Seafloor incubation experiments at deep-sea hydrothermal vents reveal distinct biogeographic signatures of autotrophic communities, FEMS Microbiology Ecology, 100(2), doi:10.1093/femsec/fiae001.

Galaska, M, **S Brown**, **S McAllister** (2023), Monitoring biodiversity impacts of a changing Arctic through environmental (e)DNA, Oceanography Special Issue, 36(2-3), 109-113, doi:10.5670/oceanog.2023.221.

Gardner, JR, JW Orr, **L Tornabene** (2023), Two new species of snailfishes (Cottiformes: Liparidae) from the Aleutian Islands, Alaska, and a redescription of the closely related *Careproctus candidus*, Ichthyology & Herpetology, 111 (1): 54-71, doi:10.1643/i2022009.

*Geng, T, F Jia, W Cai, L Wu, B Gan, Z Jing, S Li, MJ McPhaden (2023), Increased occurrences of consecutive La Niña events under global warming, Nature, 619, 774–781, doi:10.1038/s41586-023-06236-9.

Goethel, DR, KL Omori, **AE Punt**, PD Lynch, AM Berger, CL de Moor, EE Plagányi, JM Cope, NA Dowling, R McGarvey, AL Preece, JT Thorson, M Chaloupka, S Gaichas, E Gilman, S Hesp, AC Longo, N Yao, RD Methot (2023), Oceans of plenty? Challenges, advancements, and future directions for the provision of evidence-based fisheries management advice, Reviews in Fish Biology and Fisheries, 33(2), 375-410, doi:10.1007/s11160-022-09726-7.

Gold, Z, AO Shelton, HR Casendino, J Duprey, R Gallego, A Van Cise, M Fisher, AJ Jensen, E D'Agnese, EA Allan, A Ramón-Laca, M Gazber-Yonts, M Labare, KM Parsons, RP Kelly (2023), Signal and noise in metabarcoding data, PloS one, 18(5), doi:10.1371/journal.pone.0285674.

Guan, C, F Tian, MJ McPhaden, **S Hu,** F. Wang (2023), Zonal structure of tropical Pacific surface salinity anomalies affects the eastern and central Pacific El Niños differently, Geophysical Research Letters, 50, e2023GL105554, doi:10.1029/2023GL105554.

Gulland, FMD, J Robbins, **AN Zerbini,** V Andrewsgoff, M Bérubé, PJ Clapham, M Double, N Gales, AS Kennedy, S. Landry, DK Mattila, D Sandilands,JE Tackaberry, M Uhart, RET Vanstreels (2024), Effects of satellite-linked telemetry tags on humpback whales in the Gulf of Maine: Photographic assessment of tag sites. Journal of Cetacean Research and Management, (SI 5), 1-33, doi:10.47536/jcrm.v5i1.980.

*Halpern, BS, C Boettiger, MC Dietze, JA Gephart, P Gonzalez, NB Grimm, PM Groffman, J Gurevitch, SE Hobbie, KJ Komatsu, KJ Kroeker, HJ Lahr, DM Lodge, CJ Lortie, JSS Lowndes, F Micheli, HP Possingham, MH Ruckelshaus, C Scarborough, CL Wood, GC Wu, L Aoyama, EE Arroyo, CA Bahlai, EE Beller, RE Blake, KS Bork, TA Branch, NEM Brown, J Brun, et al. (2023), Priorities for synthesis research in ecology and environmental science, Ecosphere, 14(1), e4342, doi:10.1002/ecs2.4342.

Hermann, AJ, **W Cheng,** P Stabeno, **DJ Pilcher**, **KA Kearney**, KK Holsman (2023), Applications of biophysical modeling to Pacific high-latitude ecosystems, Oceanography, 36(2-3), 101-108, doi:10.5670/oceanog.2023.226.

Hoffman, CL, PJ Monreal, JB Albers, AJM Lough, AE Santoro, T Mellett, KN Buck, A Tagliabue, MC Lohan, **JA Resing,** RM Bundy (2024), Microbial strong organic ligand production is tightly coupled to iron in hydrothermal plumes, Biogeosciences, 21, 5233–5246, doi.org/10.5194/bg-21-5233-2024, doi:10.1101/2023.01.05.522639.

Hollowed, AB, KK Holsman, SP Wise, AC Haynie, **W Cheng**, DCK Evans, AJ Hermann, JN Ianelli, **KA Kearney**, **AE Punt**, JCP Reum, DL Stram, CS Szuwalski (2024), Development of climate informed management scenarios for fisheries in the eastern Bering Sea, ICES Journal of Marine Science, doi:10.1093/icesjms/fsae034.

Horne, JK, JA Swan, TJ Tracy, II, GW Holtgrieve (2023), Automated acoustic monitoring of fish for near-real-time resource management, ICES Journal of Marine Science, doi:10.1093/icesjms/fsad196.

Photo: Josh M. London/NOAA

A northern fulmar (*Fulmarus glacialis*) glides over the water in the Bering Sea with its wingtip briefly touching the surface.

Hutter, N, S Hendricks, A Jutila, R Ricker, L von Albedyll, G Birnbaum, C Haas (2023), Digital elevation models of the sea-ice surface from airborne laser scanning during MOSAiC, Scientific Data, 10(1), 729, doi:10.1038/s41597-023-02565-6.

Ioannidis, E, KS Law, J-C Raut, L Marelle, T Onishi, RM Kirpes, **LM Upchurch**, T Tuch, A Wiedensohler, A Massling, H Skov, PK Quinn, KA Pratt (2023), Modelling wintertime sea-spray aerosols under Arctic haze conditions, Atmos. Chem. Phys., 23(10), 5641-5678, doi:10.5194/acp-23-5641-2023.

*Jarugula, S, MJ McPhaden (2023), Indian Ocean Dipole affects eastern tropical Atlantic salinity through Congo River Basin hydrology, Nature Comm. Earth Environ, 4, 366, doi:10.1038/s43247-023-01027-6.

*Jiang, F, W Zhang, F-F Jin, MF Stuecker, A Timmermann, MJ McPhaden (2023), Resolving the tropical Pacific/Atlantic interaction conundrum, Geophysical Research Letters, 50, e2023GL103777, doi:10.1029/2023GL103777.

Jiang, L-Q, J Dunne, **BR Carter,** JF Tjiputra, J Terhaar, **JD Sharp**, A Olsen, S Alin, DCE Bakker, RA Feely, J-P Gattuso, P Hogan, T Ilyina, . Lange, SK Lauvset, ER Lewis, T Lovato, J Palmieri, Y Santana-Falcón, J Schwinger, R Séférian, G Strand, N Swart, T Tanhua, H Tsujino, R Wanninkhof, M Watanabe, A Yamamoto, T Ziehn (2023), Global surface ocean acidification indicators From 1750 to 2100, Journal of Advances in Modeling Earth Systems, 15(3), doi:10.1029/2022MS003563.

*Jiang, N, C Zhu, ZZ Hu, MJ.McPhaden (2024), Enhanced risk of record-breaking regional temperatures during the 2023-24 El Niño, Science Report, 14, 2521, doi:10.1038/s41598-024-52846-2.

Johnson GC and R Lumpkin, eds., with many authors, including **BR Carter** and **JD Sharp** (2023), Global oceans in state of the climate in 2022, Bulletin of the American Meteorological Society, 104(9), S146-S206, doi:10.1175/BAMS-D-23-0076.2.

Joyce, TW, MC Ferguson, CL Berchok, **DL Wright**,JL Crance, **EK Braen**, T Eguchi, WL.Perryman, DW Weller (2023), The role of sea ice in the distribution, habitat use, and phenology of eastern North Pacific gray whales, Marine Ecology Progress Series, 709, 141-158, doi:10.3354/meps14271.

Kennedy, AS, EL Carroll, **AN Zerbini**, CS.Baker, M Bassoi, NA Beretta, DL Buss, S Calderan, T Cheeseman, MA Collins, P Costa-Urrutia, P Ensor, K Groch, R Leaper, P Olson, C Passadore, FG Riet-Sapriza, E Vermeulen, F Vilches, JA Jackson (2023), Photo-identification and satellite telemetry connect southern right whales from South Georgia Island (Islas Georgias del Sur) with multiple feeding and calving grounds in the southwest Atlantic, Marine Mammal Science,1–19, doi:10.1111/mms.13089.

*Kessouri, F, MA Sutula, D Bianchi, M Ho, P Damien, JC McWilliams, CA Frieder, L Renault, H Frenzel, K McLaughlin, C Deutsch (2024), Cross-shore transport and eddies promote large scale response to urban eutrophication, Scientific reports, 14(1), 7240, doi:10.1038/s41598-024-57626-6.

Kohlman, C, MF Cronin, R Dziak, D Mellinger, A Sutton, M Galbraith, M Robert, J Thomson, **D Zhang**, and L Thompson (2023), The 2019 Marine heatwave at Ocean Station Papa: A multi-disciplinary assessment of ocean conditions and impacts on marine ecosystems, Authorea (submitted to JGR-Oceans), doi:10.22541/essoar.168881965.57429860/v1.

Lange, N, B Fiedler, M Álvarez, A Benoit-Cattin, H Benway, PL Buttigieg, L Coppola, K Currie, S Flecha, DS Gerlach, M Honda, IE Huertas, SK Lauvset, F Muller-Karger, A Körtzinger, **KM O'Brien**, SR Ólafsdóttir, FC Pacheco, D Rueda-Roa, I Skjelvan, M Wakita, A White, T Tanhua (2024), Synthesis Product for Ocean Time Series (SPOTS) – a ship-based biogeochemical pilot, Earth Syst. Sci. Data, 16, 1901–1931, doi:10.5194/essd-16-1901-2024.

Lauvset, SK, N Lange, T Tanhua, HC Bittig, A Olsen, A Kozyr, M Álvarez, K Azetsu-Scott, PJ Brown, **BR Carter**, L Cotrim da Cunha, M Hoppema, MP Humphreys, M Ishii, E Jeansson, A Murata, JD Müller, FF Pérez, C Schirnick, R Steinfeldt, T Suzuki, A Ulfsbo, A Velo, RJ Woosley, RM Key (2024), The annual update GLODAPv2. 2023: the global interior ocean biogeochemical data product, Earth System Science Data Discussions, Vol 16, Issue 4, 1-32, doi:10.5194/essd-16-2047-2024.

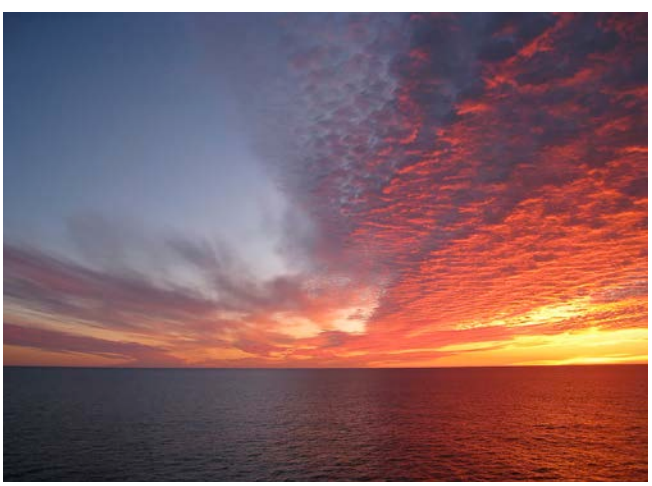


Photo: Thomas Van Pelt

Sunset over the Bering Sea.

L'Hégaret, P, F Schütte, S Speich, G Reverdin, DB Baranowski, R Czeschel, T Fischer, GR Foltz, KJ Heywood, G Krahmann, R Laxenaire, C Le Bihan, P Le Bot, S Leizour, C Rollo, M Schlundt, E Siddle, C Subirade, **D Zhang**, J Karstensen (2023), Ocean cross-validated observations from R/Vs *L'Atalante***,** *Maria S. Merian***,** and *Meteor* and related platforms as part of the EUREC4A-OA/ATOMIC campaign, Earth Syst. Sci. Data, 15(4), 1801-1830, doi:10.5194/essd-15-1801-2023.

May, SA, KR Shedd, PS Rand, PAH Westley (2023), Tidal gradients, fine-scale homing and a potential cryptic ecotype of wild spawning pink salmon (*Oncorhynchus gorbuscha*), Molecular Ecology, 32(21), 5838-5848, doi:10.1111/mec.17154.

McAllister, S, C Paight, **EL Norton**, **M Galaska** (2023), REVAMP: Rapid exploration and visualization through an automated metabarcoding pipeline, Oceanography, 36(2-3), 114-119, doi:10.5670/oceanog.2023.231.

McCabe, RM, BM Hickey, VL Trainer (2023), The Pacific Northwest Harmful Algal Blooms Bulletin, Harmful Algae, 127, doi:10.1016/j.hal.2023.102480.

*McClure, MM, CL Sabine, RA Feely, SR Hammond, C Meinig, MJ McPhaden, PJ, Stabeno, E Bernard (2023), The history and evolution of PMEL: Purposeful research that impacts environmental policy, Oceanography, 36(2–3):10–25, doi:10.5670/oceanog.2023.235.

*McElroy, KN, R Hilborn, C Cunningham, TP Quinn (2024), Brown bear (*Ursus arctos*) foraging in a mosaic of spatially discrete and variable habitats over 25 years of shifting Pacific salmon densities, Canadian Journal of Zoology, 0(0), doi:10.1139/cjz-2022-0178.

*McElroy, KN, CA Stern, TP Quinn, R Hilborn (2023), Applying the ideal free distribution to the movement of a highly mobile gillnet fishery for Pacific salmon, Canadian Journal of Fisheries and Aquatic Sciences, 81(3), 241-252, doi:10.1139/cjfas-2023-0134.

McGarvey, R, RD Methot, **AE Punt**, JM Matthews, ZIG Taylor, JE Feenstra, K Doering (2024), Performance gains from incorporating dynamic numbers by length within age in fishery assessment models, Fish Res, 276: 107039, doi:10.1016/j.fishres.2024.107039.

McHuron, EA, **M Castellote**, GK Himes Boor, KEW Shelden, AJ Warlick, TL McGuire, PR Wade, KT Goetz (2023), Modeling the impacts of a changing and disturbed environment on an endangered beluga whale population, Ecological Modelling, 483, doi:10.1016/j.ecolmodel.2023.110417.

*McInturf, AG, J Bowman, JM Schulte, KC Newton, B Vigil, M Honig, S Pelletier, N Cox, O Lester, M Cantor, TK Chapple (2023), A unified paradigm for defining elasmobranch aggregations, ICES Journal of Marine Science, 80(6), 1551-1566, doi:10.1093/icesjms/fsad099.

*McPhaden, MJ, KJ Connell, GR Foltz, RC Perez, K Grissom (2023), Tropical ocean observations for weather and climate: A decadal overview of the Global Tropical Moored Buoy Array, Oceanography, 36(2–3):32–43, https://doi.org/10.5670/oceanog.2023.211.

McWhorter, JK, HL Roman-Stork, M Le Hénaff, **H Frenzel**, MA Johnston, M Cornec, E Osborne (2024), Mesoscale eddies influence coral reef environments in the Northwest Gulf of Mexico, JGR Oceans, Vol 129, Issue 6, doi:10.1029/2023JC020821.

Mogen, SC, NS Lovenduski, S Yeager, L Keppler, **J Sharp**, SJ Bograd, N Cordero Quiros, E Di Lorenzo, EL Hazen, MG Jacox, M Pozo Buil (2023), Skillful multi-month predictions of ecosystem stressors in the surface and subsurface ocean, Earth's Future, 11(11), doi:10.1029/2023EF003605.

Monacci, NM, R Bott, JN Cross, S Maenner Jones, **S Musielewicz**, **J Osborne**, P Stabeno, AJ Sutton (2023), High-resolution ocean and atmosphere pCO2 time-series measurements from mooring GAKOA_149W_60N in the Gulf of Alaska (NCEI Accession 0116714), edited, doi:ncei.noaa.gov/archive/accession/download/116714.

Mordy, CW, NA Bond, ED Cokelet, A Deary, E Lemagie, **P Proctor**, P Stabeno, **H Tabisola**, **T Van Pelt**, E Wisegarver (2023), Progress of fisheries-oceanography coordinated investigations in the Gulf of Alaska and Aleutian passes, Oceanography, 32(2-3), 94-100, doi:10.5670/oceanog.2023.218.

Mordy, CW, D Zhang, KM O'Brien, KM Christensen, AR Gray, SC Riser (2024), Global estimates of mesoscale vertical velocity near 1,000 m from Argo observations, Journal of Geophysical Research: Oceans, 129(1), doi:10.1029/2023JC020003.

Müller, JD, N Gruber, **BR Carter**, R Feely, M Ishii, N Lange, SK Lauvset, A Murata, A Olsen, FF Pérez, C Sabine, T Tanhua, R Wanninkhof, D Zhu (2023), Decadal trends in the oceanic storage of anthropogenic carbon from 1994 to 2014, AGU Advances, 4(4), doi:10.1029/2023AV000875.

Musielewicz, S, **J Osborne,** S. Maenner Jones, **R Battisti**, **S Dougherty**, R Bott. (2023), Building unique collaborative global marine CO2 observatories, Oceanography, 36(2-3), 156-157, doi:10.5670/oceanog.2023.206.

*Nagura, M, MJ McPhaden (2023), Dual-Frequency Wind-Driven Mixed Rossby-Gravity Waves in the Equatorial Indian Ocean. J. Phys. Oceanogr., 53, 1535–1553, doi:10.1175/JPO-D-22-0222.1.

Nielsen, J, M Sigler, L Eisner, J Watson, L Rogers, S Bell, **N Pelland**, **C Mordy**, **W Cheng**, K Kivva, S Osborne, P Stabeno (2023), Spring phytoplankton bloom phenology during recent climate warming on the Bering Sea Shelf, Progress in Oceanography, 220, doi:10.1016/j.pocean.2023.103176.

Nielsen, JM, **NA Pelland**, SW Bell, MW Lomas, LB Eisner, P Stabeno, C Harpold, S Stalin, **CW Mordy** (2023), Seasonal dynamics of primary production in the Southeastern Bering Sea assessed using continuous temporal and vertical dissolved oxygen and chlorophyll-a measurements, Journal of Geophysical Research: Oceans, 128(5), doi:10.1029/2022JC019076.

*Norton, EL, IC Kaplan, S Siedlecki, **AJ Hermann**, SR Alin, J Newton, K Corbett, D Ayres, EJ Schumacker, **NA Bond**, K Richerson, MA Alexander (2023), Seasonal ocean forecasts to improve predictions of Dungeness crab catch rates, co-developed with state and tribal fishery managers, ICES Journal of Marine Science, Volume 80, Issue 4, May 2023, Pages 823–835, doi:10.1093/icesjms/fsad010.

*Oh, J-H, J-S Kug , S-I An, F-F Jin, MJ McPhaden, J Shin (2024), Emergent climate change patterns originating from deep ocean warming in climate mitigation scenarios, Nature Climate Change, doi:10.1038/s41558-024-01928-0.

Peraza, JI, **JK Horne** (2023), Quantifying conditional probabilities of fish-turbine encounters and impacts, Frontiers in Marine Science, 10, doi:10.3389/fmars.2023.1270428.

Punt, AE (2024), Stock assessment of rock lobster stocks: Past, present and future, Fish Res, 274, doi:10.1016/j.fishres.2024.106996.

Punt, AE, R Thomson, LR Little, P Bessel-Browne, P Burch, M Bravington (2024), Including close kin mark recapture data in statistical catch-at-age stock assessments and management strategies, Fish, Res. 276, doi:10.1016/j.fishres.2024.107057.

Quinn, PK, **TS Bates**, DJ Coffman, **JE Johnson**, **LM Upchurch** (2023), Climate roles of non-sea salt sulfate and sea spray aerosol in the atmospheric marine boundary layer: Highlights of 40 years of PMEL research, Oceanography, 36(2-3), 168-174, doi:10.5670/oceanog.2023.202.

Quinn, PK, **TS Bates**, DJ Coffman, **JE Johnson**, **LM Upchurch** (2024), Use of an Uncrewed Aerial system to investigate aerosol direct and indrect radiative forcing effects in the marine atmosphere,

EGUsphere, 2024, 1-20, doi:10.5194egusphere-2023-3128.
Rabe, B, CJ Cox, Y-C Fang, H Goessling, MA Granskog, M Hoppmann, JK Hutchings, T Krumpen, I Kuznetsov, R Lei, T Li, W Maslowski, M Nicolaus, D Perovich, O Persson, J Regnery, **I Rigor**, MD Shupe, V Sokolov, G Spreen, T Stanton, DM Watkins, E Blockley, HJ Buenger, S Cole, A Fong, J Haapala, C Heuzé, CJMHoppe, M Janout, et al. (2024), The MOSAiC Distributed Network: observing the coupled Arctic system with multidisciplinary, coordinated platforms, Elementa: Science of the Anthropocene, 12(1), doi:10.1525/elementa.2023.00103.
Rabinowitz, CN, SD Brown, **SM McAllister**, A. Winans, JE Keister, **MP Galaska** (2023), The complete mitochondrial genome of *Cyphocaris challengeri* (Amphipoda: Cyphocarididae), Mitochondrial DNA Part B, 8(10), 1128-1131, doi:10.1080/23802359.2023.2270206.
*Ramón-Laca, A, R Gallego, KM Nichols (2023), Affordable de novo generation of fish mitogenomes using amplification-free enrichment of mitochondrial DNA and deep sequencing of long fragments, Molecular ecology resources, 23(4), 818-832, doi:10.1111/1755-0998.13758.
Reeves Eyre, JE, MF Cronin, **D Zhang**, EJ Thompson, CW Fairall, JB Edson (2023), Saildrone direct covariance wind stress in various wind and current regimes of the tropical Pacific, Journal of Atmospheric and Oceanic Technology, 40(4), 503-517, doi:10.1175/JTECH-D-22-0077.1.
Ringeisen, D, **N Hutter**, L von Albedyll (2023), Deformation lines in Arctic sea ice: intersection angle distribution and mechanical properties, The Cryosphere, 17(9), 4047-4061, doi:10.5194/tc-17-4047-2023.
Ringham, M, N Hirtle, C Shaw, X Lu, **J Herndon**, **B Carter**, M Eisaman (2024), A comprehensive assessment of electrochemical ocean alkalinity enhancement in seawater: kinetics, efficiency, and precipitation thresholds, EGUsphere, 2024, 1-22, doi:10.5194/egusphere-2024-108.
*Rivas, PR (2023), An Index for Predicting Precipitation in the Northern Coast of Peru using Logistic Regression, Thesis, University of Washington, Seattle.
Rodgers, KB, J Schwinger, **AJ Fassbender**, P Landschützer, R Yamaguchi, H Frenzel, K Stein, JD Müller, N Goris, S Sharma, S Bushinsky, T-T-T Chau, M Gehlen, MA Gallego, L Gloege, L Gregor, N Gruber, J Hauck, Y Iida, M Ishii, L Keppler, J Kim, S Schlunegger, J Tjiputra, K Toyama, PV Ayar, A Velo (2023), Seasonal variability of the surface ocean carbon cycle: a synthesis, Global Biogeochemical Cycles, 37(9), doi:10.1029/2023GB007798.
Rone, BK, **AN Zerbini**, EA Falcone, EL Keene, GS Schorr (2024), Distribution, abundance, and density of harbor porpoises in Hood Canal, Washington, The Journal of Wildlife Management 88(3): doi:10.1002/jwmg.22543.
Ryan, C, M Santangelo, B Stephenson, **TA Branch**, EA Wilson, MS Savoca (2023), Commercial krill fishing within a foraging supergroup of fin whales in the Southern Ocean, Ecology, 104, doi.org/10.1002/ecy.4002.
Saenger, CP, P McElhany, EL Norton, DS Busch, SA Siedlecki, SR Alin, RA Feely, **AJ Hermann**, N Bednaršek (2023), Evaluating environmental controls on the exoskeleton density of larval Dungeness crab via micro computed tomography, Frontiers in Marine Science, (Feb 10), doi:10.3389/fmars.2023.1095253.
*Sauvé, J, AR Gray, CJ Prend, SM Bushinsky, SC Riser (2023), Carbon outgassing in the Antarctic Circumpolar Current is supported by Ekman Transport from the Sea Ice Zone in an observation-based seasonal mixed-layer budget, Journal of Geophysical Research: Oceans, 128(11), doi:10.1029/2023JC019815.
Schaub, M, MN Maunder, M Kéry, JT Thorson, EK Jacobson, **AE Punt** (2024), Lessons to be learned by comparing integrated fisheries stock assessment methods (SAMs) with integrated population models (IPMs), Fish, Res. 272, doi:10.1016/j.fishres.2023.106925.
Schultz, C, JP Dunne, X Liu, L Drenkard, **BR Carter** (2024), Characterizing subsurface oxygen variability in the California Current System (CCS) and its links to water mass distribution, Journal of Geophysical Research: Oceans, 129(2), doi:10.1029/2023JC020000.
Seabrook, S, M Torres, T Baumberger, **D Butterfield**, K Roe, S Cummings, R Crawford, A Thurber (2024), Ubiquitous but unique: water depth and oceanographic attributes shape methane seep communities, Limnol, Oceanogr, doi:10.1002/lno.12564. 2024-1392.
Sellinger, EL, C Szuwalski, **AE Punt** (2024), The robustness of our assumptions about recruitment: A re-examination of marine recruitment dynamics with additional data and novel methods, Fisheries Research, 269, doi:10.1016/j.fishres.2023.106862.
Sharp, JD, AJ Fassbender, **BR Carter**, GC Johnson, C Schultz, JP Dunne (2023), GOBAI-O 2: temporally and spatially resolved fields of ocean interior dissolved oxygen over nearly two decades Earth System Science Data, 15 (10), doi:10.5194/essd-15-4481-2023.

Siddon, E, CJ Cunningham, T Hennon, J Ianelli, **K Kearney**, N Monacci, **CW Mordy**, **JM Nielsen**, R Thoman, **M Wang**, **GA Whitehouse** (2023), Ecosystem Status Report 2022: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501, doi:https://appsafsc.fisheries.noaa.gov/Plan_Team/2022/EBSecosys.pdf.

Siedlecki, SA, SR Alin, **EL Norton**, NA Bond, **AJ Hermann**, RA Feely, JA Newton (2023), Can seasonal forecasts of ocean conditions aid fishery managers? Experiences from 10 years of J-SCOPE, Oceanography, 36(2-3), 158-167, doi:10.5670/oceanog.2023.219.

*Spencer, LH, WC Long, IB Spies, KM Nichols, RJ Foy, (2024), Narrowed gene functions and enhanced transposon activity are associated with high tolerance to ocean acidification in a juvenile subarctic crustacean, PLOS Climate, 3(3), doi:10.1371/journal.pclm.0000319.

*Sprintall, JN, M Agura, J Hermes, MK Roxy, MJ McPhaden, E Pattabhi Ram Rao, T Srinivasa Kumar, S Thurston, J Li, M Belbeoch, V Turpin (2024), COVID impacts cause critical gaps in the Indian Ocean observing system, Bull. Amer. Meteor. Soc., 105, E725–E741, ,doi:10.1175/BAMS-D-22-0270.1.

Stabeno, PJ, **RM McCabe** (2023), Re-examining flow pathways over the Chukchi Sea continental shelf. Deep-Sea Res. II, 207, 105243, doi:10.1016/j.dsr2.2022.105243.

Stabeno, P, S Bell, C Berchok, ED Cokelet, J Cross, RM McCabe, **CW Mordy**, J Overland, D Strausz, M Sullivan, **HM Tabisola** (2023), Long-term biophysical observations and climate impacts in US Arctic marine ecosystems, Oceanography, 36(2-3), 78-85, doi:10.5670/oceanog.2023.225.

Stalin, S, S Bell, N Delich, **CW Mordy**, J Stabeno, **HM Tabisola**, D. Tagawa (2023), Advancing observational infrastructure in the Arctic, Oceanography, 36(2-3), 86-87, doi:10.5670/oceanog.2023.227.

Stepien, CA, HK Schultz, **SM McAllister**, **EL Norton**, JE Keister (2024), Evaluating metabarcoding markers for identifying zooplankton and ichthyoplankton communities to species in the Salish Sea: morphological comparisons and rare, threatened or invasive species, DNA, 4(1), 1-33, doi:10.3390/dna4010001.

Sucunza, F, D Danilewicz, PH Ott, M Neves, AC Farro, AS Martins, **AN Zerbini** (2023), Distribution, population size and IUCN Red Listing of an isolated population of the threatened franciscana, Endangered Species Research, Vol. 52: 17–26, doi:10.3354/esr01262.

Sweeney, AJ, Q Fu, S Po-Chedley, H Wang, **M Wang** (2024), Unique temperature trend pattern associated with internally driven global cooling and Arctic warming during 1980-2022, ESS Open Archive, doi:10.22541/essoar.170808511.12522359/v1.

Sweeney, AJ, Q Fu, S Po-Chedley, H Wang, **M Wang** (2023), Internal Variability Increased Arctic Amplification during 1980–2022, Geophysical Research Letters, 50(24), doi:10.1029/2023GL106060.

Tabisola, HM, **CW Mordy**, S Stalin (2023), Accelerating research and development in the US Arctic: Reflections on a NOAA program, Oceanography, 36(2-3), 216-221, doi:10.5670/oceanog.2023.232.

*Tan, W, Z-Z Hu, MJ McPhaden, C. Zhu,, X Li, Y Liu (2024), On the divergent evolution of ENSO after the coastal El Niños in 2017 and 2023, Geophysical Research Letters, 51, e2024GL108198, doi:10.1029/2024GL108198.

Teleti, P, E Hawkins, **KR Wood** (2023), Digitizing weather observations from World War II US naval ship logbooks, Geoscience Data Journal, 0, 1-16, doi:10.1002/gdj3.222.

ten Brink, U, J Chaytor, C Flores, **Y Wei**, S Detmer, L Lucas, B Andrews, A Georgiopoulou (2023), Seafloor observations eliminate a landslide as the source of the 1918 Puerto Rico Tsunami, Bull, Seismol. Soc. Am., 113(1), 268-280, doi:10.1785/0120220146.

*Thoman, RL, TA Moon, ML Druckenmiller, Eds. (2023), Arctic Report Card 2023, https://arctic.noaa.gov/report-card/report-card-2023/about-arctic-report-card-2023/, doi:10.25923/5vfa-k694.

*Timm, LE, N Tucker, A Rix, S LaBua, JA López, KM Boswell, JR Glass (2023), The untapped potential of seascape genomics in the North Pacific, Frontiers in Conservation Science, 4, doi:10.3389/fcosc.2023.1249551.

Titov, VV, C Meinig, S Stalin, **Y Wei**, C Moore, E Bernard (2023), Technology transfer of PMEL tsunami research protects populations and expands the new blue economy, Oceanography, 36(2-3), 186-195, doi:10.5670/oceanog.2023.205.

*Tozuka, T, T Toyoda, MF Cronin (2023), Role of mixed layer depth in Kuroshio Extension decadal variability, Geophys. Res. Lett., 50(12), e2022GL101846, doi:10.1029/2022GL101846.

Vermeulen, E, M Germishuizen, A Kennedy, C Wilkinson, CR Weir, **AN Zerbini** (2024), Swimming across the pond: First documented transatlantic crossing of a southern right whale, Marine Mammal Science, 10.1111/mms.13089, 40, 2, doi:10.1111/mms.13071.

Vilches, FO, M Sironi, **AN Zerbini**, SJ Fernández, M Uhart, VJ Rowntree (2023), Life histories of satellite-tracked Southern Right Whales through photo-identification and citizen science in Patagonia, Argentina, Aquatic Mammals 49(2): 167-76, doi:10.1578AM.49.2.2023.167.

*Virdin, J, X Basurto, G Nico, S Harper, M del Mar Mancha-Cisneros, S Vannuccini, M Ahern, CM Anderson, S Funge-Smith, NL Gutierrez, DJ Mills, N Franz (2023), Fishing for subsistence constitutes a livelihood safety net for populations dependent on aquatic foods around the world, Nature Food, 4(10), 874-885, doi:10.1038/s43016-023-00844-4.

*Wang, B, W Sun, C Jin, X Luo, YM Yang, T Li, B Xiang, MJ McPhaden, MA Cane, FF Jin, F Liu, J Liu (2023), Understanding the recent increase in multiyear La Niñas. Nature Climate Change, 13, 1075–1081, doi: 10.1038/s41558-023-01801-6.

Wang, M, J Overland (2023), Arctic research at PMEL: From sea Ice to the stratosphere, Oceanography, 36(2-3), 88-93, doi:10.5670/oceanog.2023.228.

Wang, W, AJM Lough, H Goring-Harford, O Flanagan, D González-Santana, **J Resing**, D Connelly, MC Lohan, A Tagliabue, RH James (2023), Fractionation of iron and chromium isotopes in hydrothermal plumes from the northern Mid-Atlantic Ridge, Earth and Planetary Science Letters, 624, doi:10.1016/j.epsl.2023.118468.

Wanninkhof, R, JA Triñanes, P Landschützer, RA Feely, **BR Carter** (2023), Global ocean carbon cycle in State of the Climate in 2022, Bulletin of the American Meteorological Society, 104(9), S191–S196, doi:10.1175/BAMS-D-23-0076.2.

Wei, Y, US ten Brink, BF Atwater (2024), Modeled flooding by tsunamis and a storm versus observed extent of coral erratics on Anegada, British Virgin Islands—further evidence for a great Caribbean earthquake six centuries ago, Journal of Geophysical Research: Solid Earth, 129(3), doi:10.1029/2023JB028387.

Wills, SM, MF Cronin, **D Zhang** (2023), Air-sea heat fluxes associated with convective cold pools, Journal of Geophysical Research: Atmospheres, 128(20), doi:10.1029/2023JD039708.

*Wilson, EA, DB Bonan, AF Thompson, N Armstrong, SC Riser (2023), Mechanisms for abrupt summertime circumpolar surface warming in the Southern Ocean, Journal of Climate, 36(20), 7025-7039, doi:10.1175/JCLI-D-22-0501.1.

Wright, DL, DG Kimmel, M Roberson, D Strausz (2023), Joint species distribution modeling reveals a changing prey landscape for North Pacific right whales on the Bering Shelf, Ecological Applications 33(8): e2925, doi:10.1002/eap.2925.

Xiang, Y, PD Quay, **RE Sonnerup**, AJ Fassbender (2023), Subtropical gyre Nnutrient cycling in the upper ocean: insights from a nutrient-ratio budget method, Geophysical Research Letters, 50(13), doi:10.1029/2023GL103213.

Young, NC, AA Brower, MM Muto, JC Freed, RP Angliss, NA Friday, PL Boveng, BM Brost, MF Cameron, JL Crance, SP Dahle, BS Fadely, MC Ferguson, KT Goetz, M London, EM Oleson, RR Ream, EL Richmond, KEW Shelden, KL Sweeney, RG Towell, PR Wade, JM Waite, **AN Zerbini** (2023), Alaska marine mammal stock assessments, doi:10.25923/ds2w-9545.

*Zahner, JA, TA Branch (2024), Management strategy evaluation of harvest control rules for Pacific Herring in Prince William Sound, Alaska, ICES Journal of Marine Science, 81(2), 317-333, doi:10.1093/icesjms/fsad199.

*Zhai, S, W Swanson, JR McConnell, N Chellman, T Opel, M Sigl, H Meyer, X Wang, L Jaeglé, J Stutz, JE Dibb, K Fujita, B Alexander (2023), Implications of snowpack reactive bromine production for Arctic ice core bromine preservation, Journal of Geophysical Research: Atmospheres, 128(20), doi:10.1029/2023JD039257.

Zhang, C, G Foltz, **AM Chiodi**, **CW Mordy**, CR Edwards, C Meinig, **D Zhang**, E Mazza, ED Cokelet, EF Burger, F Bringas, GJ Goni, HG Hristova, H-S Kim, JA Trinanes, JA Zhang, KE Bailey, **KM O'Brien**, M Morales-Caez, M Lawrence-Slavas, R Jenkins, SS Chen, X Chen (2023), Hurricane observations by uncrewed systems, Bulletin of the American Meteorological Society, 104(10), E1893-E1917, doi:10.1175BAMS-D-21-0327.1.

Zhang, D, **A Chiodi**, C Zhang, G Foltz, M Cronin, **CW Mordy**, J Cross, E Cokelet, J Zhang, C Meinig, N Lawrence-Slavas, P Stabeno, and R Jenkins (2023), Observing extreme ocean and weather events using innovative saildrone uncrewed surface vehicles, Oceanography, 36(2-3), 70-77, doi:10.5670/oceanog.2023.214.

Zhang, J, W Cheng, P Stabeno, M Veneziani, W Weijer, **RM McCabe** (2024), Understanding ocean stratification and its interannual variability in the northeastern Chukchi Sea, Front. Mar. Sci., Sec. Physical Oceanography, Volume 11 – 2024, doi:10.3389/fmars.2024.1415021.

*Zhang, L, C Wang, W Han, MJ McPhaden, A Hu, W Xing (2023), Emergence of the Central Atlantic Niño. Sci. Adv., 9, eadi5507, doi:10.1126/sciadv.adi5507.

Zhang, X, X Chen, A Orr, JE Overland, T Vihma, **M Wang**, Q Yang, R Zhang (2023), Preface to the Special Issue on Changing Arctic Climate and Low/Mid-latitudes Connections, Adv. Atmos. Sci., 40(12), 2135–2137, doi:10.1007/s00376-023-3015-8.

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