CURRENT TIDES

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Doug Wallace
Chair of the Department of Oceanography

KUDOS AND THANKS TO OUR KNOWLEDGE GENERATORS!

I'm writing this foreword under less than ideal circumstances. Following on from the tragedy of losing a dear colleague and friend, we are now in the situation where Faculty are locked out of the University so that they cannot access buildings or email, talk with their students or teach. In the midst of these demotivating circumstances, it is a fillip and joy to read the new edition of Current Tides and see what our Department's graduate students are doing, and how well they communicate about it.

I finished my time as a grad student in the Department an astonishing (to me) 40 years ago. After 24 years away in the USA and Germany, I returned to where I started because of the Department's strength and breadth and its potential to make a difference on the global stage.

The basis for the Department's strength has always been its graduate students: the knowledge generators. Our graduate program is demanding, for sure, but the quality is high and is recognized widely. The department has always sought to be interdisciplinary, but based on disciplinary strength. Reading the articles in this issue of Current Tides, I get the feeling that we may have reached new heights.

The articles highlight both the quality and interdisciplinarity of our department's research and its relevance from local to global scales. As a chemical oceanographer, it's truly gratifying to read articles by biological oceanographers (Jessica) and physical oceanographers (Ruby and Josiane) that discuss alkalinity. That would not have happened 40 years ago! It's also impressive to see application of models at different scales, in close combination with observations, to a variety of practical problems that connect ocean physics with chemistry and biology (Jacob, Josiane, Graeme). Kevan's article transports us to the Pacific Ocean and keeps zooplankton, and their role in the ocean food chain, in focus: another topic with a long history in our Department. Madeline and Lina report on their use of field observations to shed light on difficult to measure and climate-sensitive, high-latitude processes (mixing and carbon transport). Finally, I appreciated Emily's telling her tale of determination in recovering hard-won data collected in the 1960's by researchers who are now deceased. So many lessons in her article ring true to me, including the intergenerational value of ocean data and the importance of data archival, but also the scientific value of being stubborn.

Thanks to all the authors and the production team of Current Tides for demonstrating why we can be so proud of the Oceanography Department and its research effort.

Doug Wallace

Monika Neufeld | Editor-in-chief
Monika was born in Calgary, Alberta but was raised in the Annapolis Valley, Nova Scotia. Her interest in ocean science began in high school and brought her to Dalhousie University for her bachelor degree in marine biology. Her honours project was her first introduction to deep-sea hydrothermal vent research and she has not looked back since. Monika is an outdoor enthusiast, and never tires of exploring the coastlines above and below the water.

Wendy Muraoka | Co-Editor-in-chief
Wendy grew up in San Jose, California and the first goals she ever really had were to become a paleontologist and a mermaid. Well, her feet never became fins, and she was disappointed to learn that most dinosaurs were now buried out in the desert, but paleoceanography, working out at sea and studying how species interacted across time, offers a happy medium. Wendy loves to travel, play D&D, and spend as much time in the water as possible.

LETTER FROM THE EDITOR IN CHIEF

Much like the ocean – dynamic, vast, and in constant flux – this volume of Current Tides captures the last three years of ebbs and flows of our lives as graduate students in the Department of Oceanography. Working in leaky basement labs, windowless offices, and always chasing knowledge and discovery at the edge of the horizon. Just as tides shift and ecosystems change, so too have the students, mentors, and stories behind each article.

We are proud to share this body of work – not as a final product, but as a snapshot in the evolving story of early-career ocean scientists. Public outreach and communication are cornerstones of any good science and Current Tides showcases innovation and rigorous scientific inquiry alongside the students dedicating their lives to it. We are so proud of everyone involved. From the writers who poured themselves onto the page and worked to make their science easily understandable for anyone interested, to the editors who gave their time and energy polishing each story, to our graphic designer who turned our hours in the lab, on ships, and in our offices staring at computer screens covered in data and half written manuscripts, into a work of art. Thank you for your dedication and passion. Thank you to the Department of Oceanography and our generous sponsors for your continued support that helps make this endeavor possible.

And thank you, our reader, for joining us in celebrating the curiosity, dedication, and passion that fills these pages. We hope you enjoy this, our sixth volume, of Current Tides.

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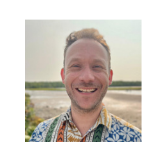
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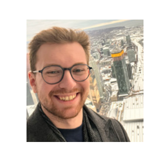
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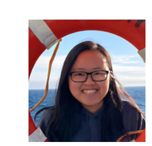
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Markus Kienast

11 August, 1969 – 12 July, 2025

WE DEDICATE THIS ISSUE OF CURRENT TIDES TO MARKUS KIENAST

On July 12, as the birds joined in wonderful morning chorus, we lost colleague, mentor and friend, Markus Kienast. Markus was a lover of life, and luckily for us, he brought that love with him to work every day. Markus was intellectually curious, critical (in the good way) and kind. And he was a community builder who was deeply committed to making our Department fair, rigorous and welcoming. Over his more-than-two decades in Oceanography, Markus guided numerous students and postdocs, and he collaborated extensively in his scientific inquiries. His door was always open, whether you needed a laugh, advice, support, or you simply wished to talk about the carbonate buffer system. But Markus also engaged willingly and actively in the less heralded work that is so essential to a thriving academic mission. He spent years doing the heavy lifting of allocating space, and his good-natured approach left us all feeling like we were being treated fairly. He served as Graduate Coordinator, making great advances in strengthening and standardizing our degree programs. Markus spearheaded the remarkably successful TOSST/HOSST graduate exchange program between Dalhousie and Kiel, whose legacy of collaboration continues. Markus encouraged us to meet over coffee, and to kick the ball around the soccer pitch. By analogy, Markus arrived here in 2004, and immediately set to work to enrich and till our Departmental earth. The fruits of his labour grow all around us. For that, Markus, we thank you. This Current Tides is dedicated to you.

Dr. Paul Hill
Professor in the Department of Oceanography
Loving friend and colleague of Markus

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It's an honor to contribute this note for Volume 6 of Current Tides, as my connection to this magazine, to DOSA, and to the entire Department of Oceanography, runs deep.

During my time in DOSA—2009-2015—my research in chemical oceanography involved carbon and isotopes, and to outside audiences it was, well.. pretty dry. I, like most grad students, really struggled to write about the research. What I enjoyed instead was talking about it, presenting it. I enjoyed explaining my work in ways people could understand, and above all, I enjoyed exuding my passion and enthusiasm for it. Oceanography is, after all, incredibly complex and amazing!

Writing for Current Tides represented my first real foray in written science communication. Not a brutally technical conference abstract, lit review, manuscript, proposal, or thesis, but accessible writing with some actual pizzazz and enthusiasm. Something that represented my personality, rather than conforming to academic 'standards'. For this reason I loved my Current Tides article, "The Radium Stopwatch: Using decaying isotopes to understand marine inputs of a key greenhouse gas" (I still have my copy!). I remain really proud of it.

Effectively communicating the complexity of one's ocean research, in speech, text, or otherwise, is a skill that I believe is equally valuable to the research skills themselves. This skill is a muscle that needs training, though universities typically provide few training opportunities. Recognizing that I wanted to hone this skill, I sought out opportunities, and it has consistently helped me on my career trajectory. That trajectory took a fairly abrupt turn in late 2022 when I decided to leave academia and join a small Dartmouth-based startup company called Planetary as their first oceanographer on staff. It was a very scary move at the time, but it brought me back to Halifax, directly into research with my old colleagues and friends at Dalhousie Oceanography. My new role was pretty simple: accelerate the very early Dalhousie-Planetary joint research into this exciting new concept called carbon dioxide removal (CDR), and specifically a marine CDR approach called Ocean Alkalinity Enhancement, or OAE.

The concept of OAE is simple: by speeding up one of the oceans natural carbon cycles just a tiny bit, you can remove a significant amount of CO_2 from the atmosphere while also alleviating some of the damaging impacts of ocean acidification. It's a potential win-win, and harnessing the scale of the oceans, it has the potential to make a real climate-scale impact. So it comes as no surprise that Planetary, a small Halifax-based startup company, has the stated vision to "protect and restore the ocean and climate for generations to come." It's a small team with big goals, and through global collaborations (Dalhousie being by far one of the biggest and most impactful), we've made some seriously exciting progress.The work being done in Halifax is widely recognized as world-leading, and you will read about some of that world-leading OAE research in this year's Current Tides edition!

Thank you Monika for your hard work and dedication to keeping Current Tides flowing!

Will Burt
VP Science and Product | Planetary Tech

Basin Sized Approaches to a Global Problem

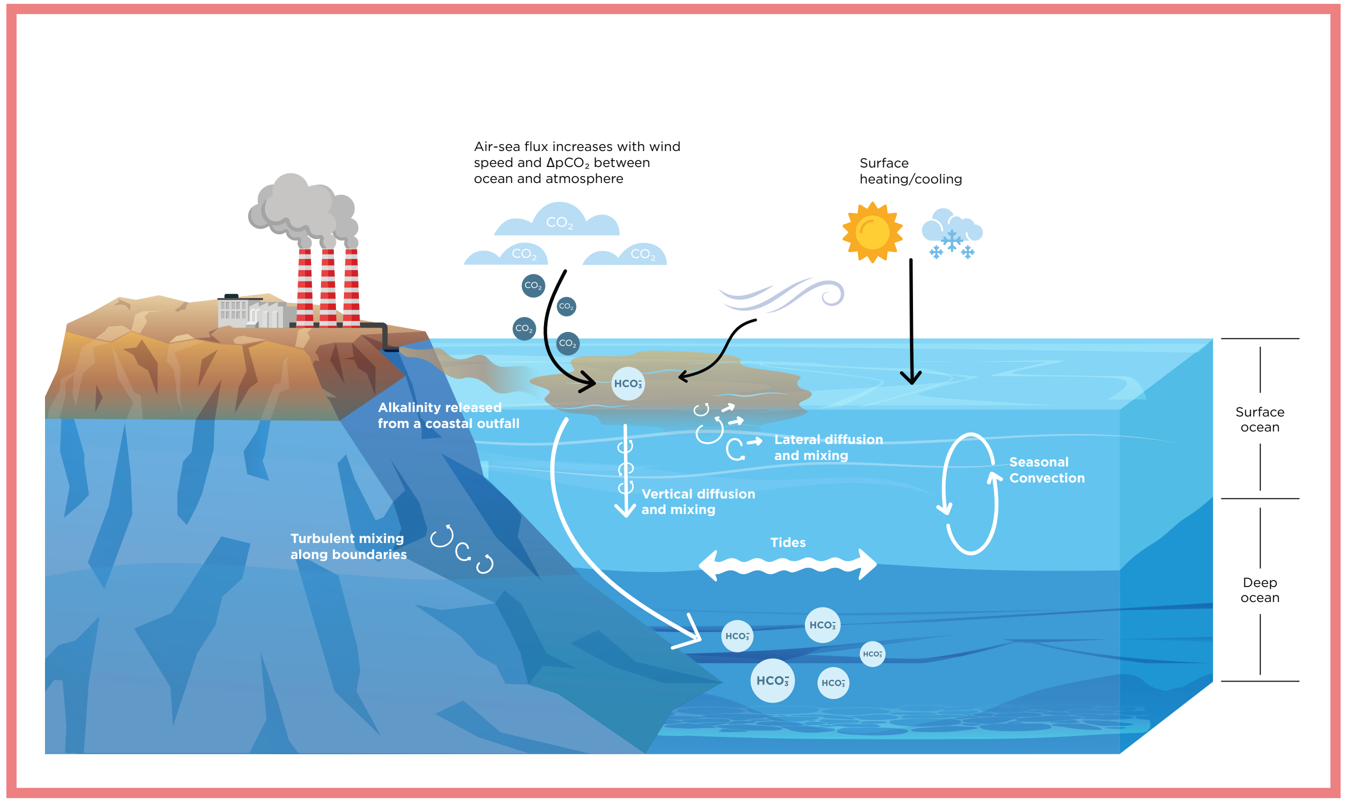
Ruby Yee

Image credit: Dalhousie University

THE AMOUNT OF anthropogenic carbon in the atmosphere is increasing, and the effects are undeniable. Over the last century, global temperatures have increased due to the greenhouse effect, and extreme weather events have become more frequent. In the ocean, sea ice is melting and coral reefs are bleaching. Most experts agree that promises made by many countries to curb carbon emissions—even if they are met—won't be sufficient to meet our future climate goals. The problem is obvious… but what can be done to divert ourselves from this increasingly grim trajectory? According to a 2022 report released by The National Academy of Sciences, Engineering, and Medicine, efforts will be needed to actively remove carbon dioxide (CO_2) from the atmosphere. Since the vast inorganic carbon reservoir of the ocean is over forty times larger than the entire atmospheric reservoir, it has been identified as an ideal location for safe, long-term storage—thus, the amount of atmospheric carbon that would need to be removed would have negligible effects on the ocean as a whole. This approach, known as marine carbon dioxide removal, sounds promising. But how do we go about safely and effectively moving carbon from the atmosphere into the ocean? This is where my research on ocean alkalinity enhancement begins.

OCEAN ALKALINITY ENHANCEMENT: IT'S GOOD TO BE BASIC

But first—I'll dig a little deeper into the process of carbon storage, starting with a key concept: alkalinity. Alkalinity is a measure of excess dissolved substances in the water that control the chemical dissociation of carbonic acid, H_2CO_3, which is formed when CO_2 gas dissolves in water. As alkalinity is increased—for instance, by adding a base, like hydroxide, to the water—more carbonic acid dissociates, and as a result, more carbon is stored in the water as carbonate and bicarbonate. A more alkaline solution will be rich in these forms of carbon and lower in dissolved CO_2 and H_2CO_3. This is why alkalinity is so relevant to carbon storage, because a CO_2 deficit in the surface waters (relative to the conditions prior to adding a source of alkalinity) will initiate a transport of CO_2 from the atmosphere to the ocean as the system attempts to return to equilibrium.



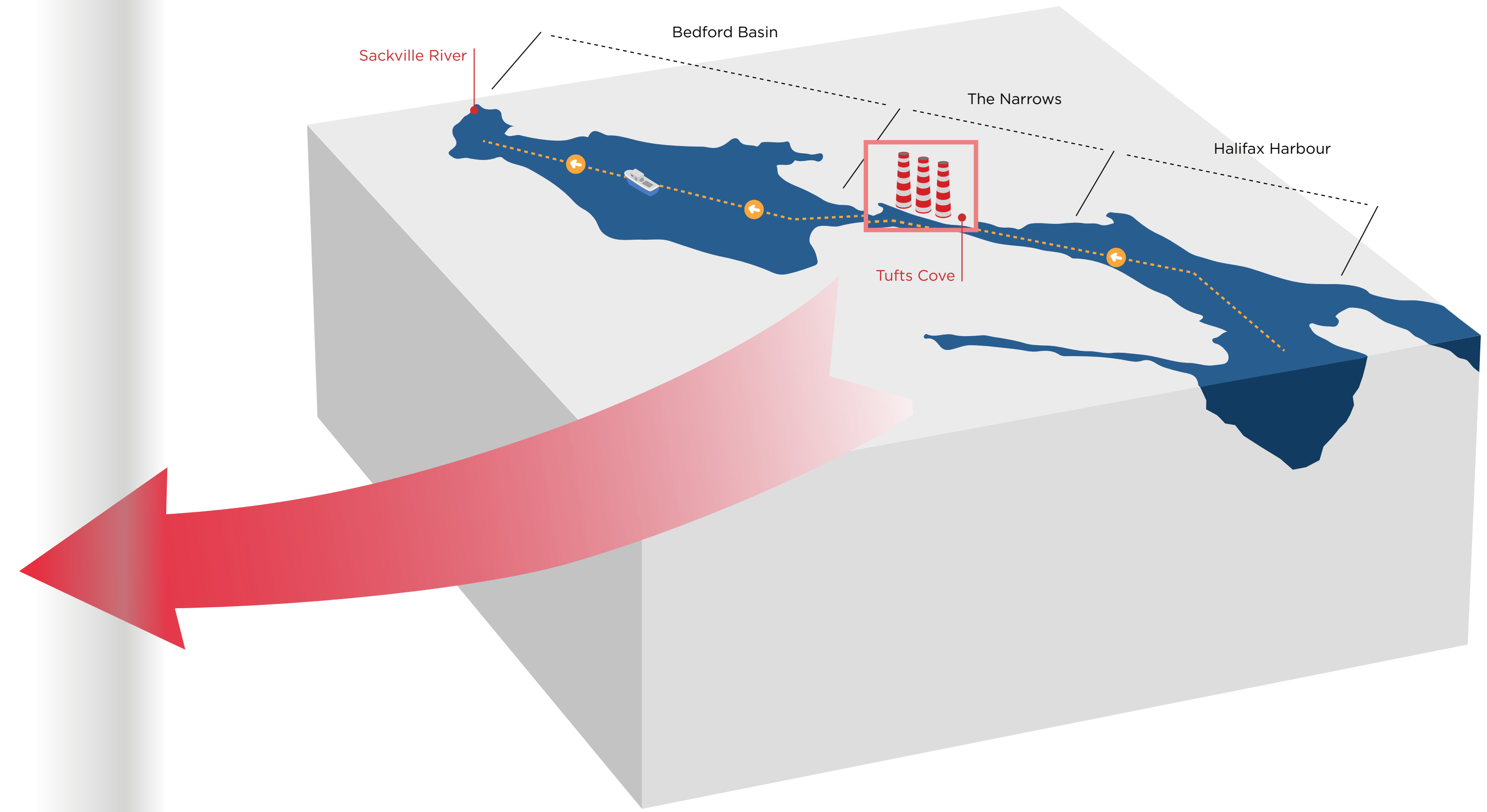
Alkalinity released from a coastal outfall pipe induces a CO_2 deficit in the surface layer, resulting in an influx of CO_2 from the atmosphere. Physical forcings like tides, wind, and convection due to air temperature changes cause mixing and dilution of the plume, which—along with other factors like wind speed—affects the rate of air-to-sea carbon flux.

This process is constantly occurring in nature. Mineral weathering on land delivers alkalinity to the ocean via rivers and runoff, playing a role in the natural carbon cycle by removing CO_2 from the atmosphere. But the timescales required for CO_2 removal render these natural processes virtually irrelevant in the short term. By comparison, a method known as ocean alkalinity enhancement (OAE) speeds up this process through the deliberate addition of alkalinity to the surface ocean, where it reacts with CO_2 that is already dissolved in the water. Just like in the natural process, the CO_2 is transformed into other carbon molecules (like carbonate and bicarbonate), making room for more CO_2 to be stored. In this way, OAE can be seen to supplement — or enhance, as the name suggests — the natural process for removing CO_2 from the atmosphere and storing it in the ocean.

PROCEEDING WITH CAUTION

Unsurprisingly, there are some subtleties here. Although the process works in theory, there is a lot of groundwork to be done before alkalinity could possibly be added to the ocean at large scales.

You might be thinking that it sounds risky, or even irresponsible, to dump environment-altering chemicals into natural bodies of water. We can recall several times in the past when this same premise went sideways, including controversial ocean iron fertilization experiments over the last few decades. OAE is a relatively young technology, meaning that we still have the opportunity for preliminary research before moving on to large-scale experiments. Monitoring, reporting, and verification — often abbreviated to MRV — is hot right now in the field of CO_2 removal research. As a general concept, MRV encompasses the spirit of being careful and responsible through rigorous early-stage research.

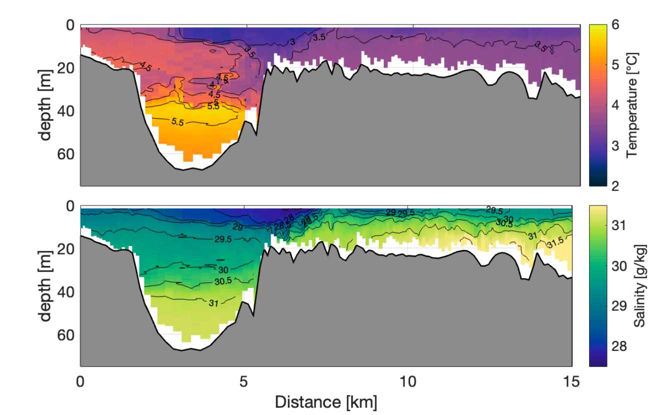


Tufts Cove, located in the Narrows of Halifax Harbour, is proposed as a site for alkalinity enhancement experiments. For the field work described in this article, we measured ocean temperature, salinity, and other variables from a boat as it transited along the yellow track shown here.

The body of research that lies ahead is sprawling and interdisciplinary. I am a physical oceanographer, so my attention is to the physical processes at play that could affect the success of OAE, from tides to wind to ocean heat and salt content. In my research, I approach MRV in two ways: through field observations, and using computer models.

UNCOVERING THE DYNAMICS OF HALIFAX HARBOUR (WITH THE HELP OF A CHINESE SEA GODDESS)

Although OAE attempts to tackle a global issue, we must first verify that the method works at small, manageable scales. Halifax Harbour and Bedford Basin comprise a semi-enclosed coastal estuary that has been proposed as an ideal OAE test site by the company Planetary Technologies. This is where my research comes in. It's important to understand the baseline conditions and circulation patterns prior to conducting any



Temperature and salinity in January 2024, collected along the dashed yellow survey track shown on the schematic at the top of the page. These transects are comprised of vertical profiles obtained during a day of surveying with Mazu (distance 0 km = Sackville River; 15 km = Halifax Harbour). Credit: Ruby Yee experiments, so we have undertaken a monthly survey campaign in this region over the past few years. We hope to use the observations to answer questions like: How do the physical characteristics of the basin change seasonally? What is its natural extent of variability in temperature, salinity, and CO_2 content? And, how quickly would an added alkalinity-enhancing substance spread and mix with the surrounding waters?

On a given day of surveying, we start by setting up our instrument, which measures temperature, salinity, and dissolved oxygen, on what is essentially a big fishing reel. The instrument, which we have affectionately named "Mazu" after a Chinese sea goddess, is then lowered to the sea floor and reeled back to the surface repeatedly as our survey vessel, the Eastcom, transits from the top of Bedford Basin all the way down to McNabs Island, yielding full-depth profiles of temperature, salinity, and oxygen throughout the basin and Halifax Harbour. Sensors measuring chemical parameters, such as pH and CO_2, are also lowered into the water at a few stops along the way. Observations from these surveys help us understand how the basin and harbour change seasonally, and the extent to which properties like temperature and salinity vary in space. Wind, tides, and changing air temperatures can dramatically alter the physical environment from one month to the next.

One of the more visually striking field experiments we have undertaken involved releasing a non-reactive pink dye called Rhodamine into the constricted passage known as The Narrows that connects Bedford Basin to Halifax Harbour. The dye was added to a cooling water discharge pipe at the nearby Tufts Cove power generating station. The dye release was a useful dress-rehearsal for alkalinity additions, since coastal wastewater outfalls have been suggested as convenient places where OAE could occur.

After equipping Mazu with a shiny new sensor that uses fluorescence to measure Rhodamine concentration, we tracked the dispersion of the dye to infer properties like diffusivity — that is, how much a substance added to the water spreads out over a given time. Estimates of diffusivity can be used to predict how the concentration of a substance like alkalinity will evolve over time following a release, and whether it will remain near the surface or be transported deeper into the water column.

Underway during surveying—Mazu is submerged in the water, connected to the winch by a thin line. Credit: Dalhousie University

Preparing Mazu (the silver cylinder) for a day of surveying. Credit: Dalhousie University

THE CONVENIENCE OF COMPUTER MODELING

The cost and logistics of ship-based surveys limit how often we can make observations, and experiments with alkalinity release require extensive planning, people, and cooperation with local agencies. In comparison, computer models are a convenient way to run experiments without all the fuss. We can initialize a computer model by feeding in real information about the environment (like water temperature, salinity, wind, and tides). The survey observations provide a reference for the model results, so that we can apply any necessary adjustments to the model and eventually gain confidence in our simulated outputs.

The useful (and fun) part comes when we manipulate properties in the simulation that may not be easy to manipulate in real life. For instance, we can add any quantity of dye or alkalinity at any location within the model domain and watch how long it takes for the system to re-equilibrate. Using models, we can ask questions like, how long would it take for the alkalinity to mix through the water column if the winds were three times stronger? or how is dilution affected due to surface cooling during winter versus heating during summer? These kinds of questions can, conveniently, be addressed using a well-designed model and a powerful computer in a matter of hours.

Attaching Mazu to the winch. Credit: Dalhousie University

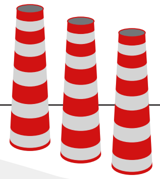
The crew aboard the Eastcom observes the edge of the Rhodamine plume during a dye release experiment.
Image credit: Dalhousie University

LOCATION IS EVERYTHING

If OAE is to be scaled up, with many alkalinity addition sites established regionally or globally, it's worth thinking about what properties might make a location suitable (that is, most efficient) for carbon storage. Wind is one example of a site-specific property that could matter a lot for OAE efficiency. We know that the rate at which CO_2 is drawn down from the atmosphere depends on the wind speed, because higher winds mean more waves, mixing, and CO_2 flux from air to sea. But strong winds can also cause a deepening of the near-surface mixed layer. This layer, which encompasses all of the water that is regularly in contact with the atmosphere, is where we ideally want all of the added alkalinity to remain.

A thin mixed layer is probably good for OAE because alkalinity added at the surface would remain in near-constant contact with the atmosphere, fulfilling its intended purpose of drawing down atmospheric CO_2. In comparison, a parcel of water residing in a deeper mixed layer will spend less time in contact with the atmosphere, and so any alkalinity added to such a layer would take longer to draw down the same amount of CO_2.

But perhaps a bigger threat to CO_2 storage efficiency is the transport of alkalinity out through the bottom of the mixed layer. Alkalinity that escapes the mixed layer before it can react with CO_2 has essentially zero short-term potential for removing carbon from the atmosphere. This means that avoiding locations with strong vertical transports might be the best choice if we are to optimize CO_2 removal. Regions with particularly strong vertical density gradients are likely to yield the highest carbon removal efficiencies, since strong stratification tends to isolate ocean layers from one another, thus inhibiting vertical mixing.



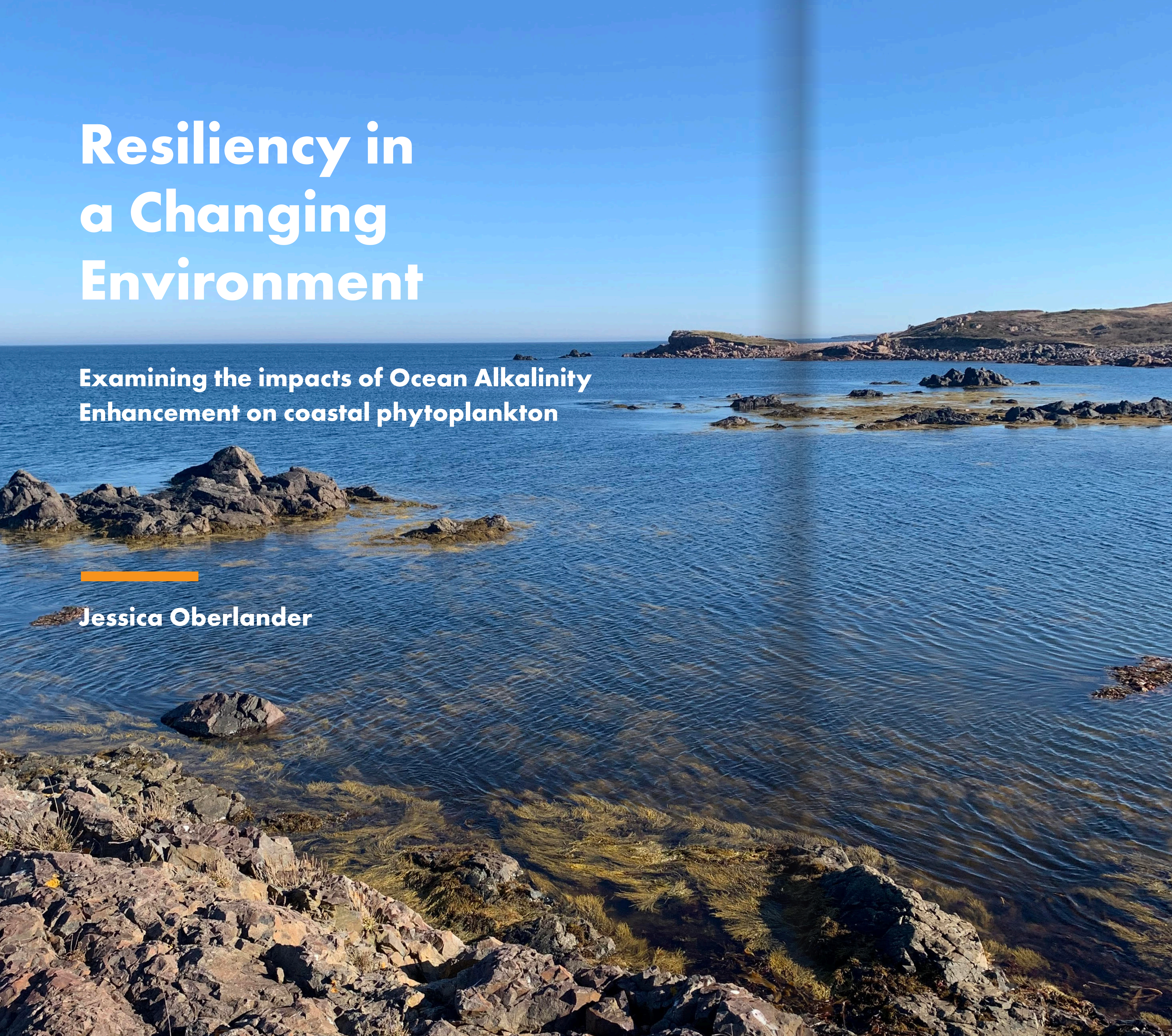
THE BIGGER PICTURE

It is risky to pin too much hope on a single climate solution, and it is certainly too early to tell whether OAE will be a safe and effective method for removing CO_2 from the atmosphere. OAE should also not be used as an excuse for industries to continue producing carbon emissions without restraint—rather, it must be viewed as a tool that could complement other efforts at emissions reduction. As researchers, we must also be willing to accept the possible outcome that OAE should not be used.

Safe or unsafe? Effective or not? Ultimately, all of these efforts, from surveying with Mazu in the field to computer modeling in the lab, attempt to answer these questions. Of course, I want OAE to work. I want it to be effective at removing carbon from the atmosphere, without causing any serious adverse effects to the ocean ecosystem. Although it's unlikely to be the one single solution to climate change, I approach my research with a sense of cautious optimism. It is useful to remind ourselves that tackling a problem as vast as the ocean must start with basin-sized solutions.

Tufts Cove power generating station, located in the Narrows. During the dye release experiments and eventual alkalinity enhancement experiments, dye/alkalinity is added to the outfall pipe near the shoreline (where a bubbly white surface plume can be seen).
Credit: Dalhousie University

The Eastcom, underway in Halifax Harbour.
Credit: Dalhousie University



Resiliency in a Changing Environment

Examining the impacts of Ocean Alkalinity Enhancement on coastal phytoplankton

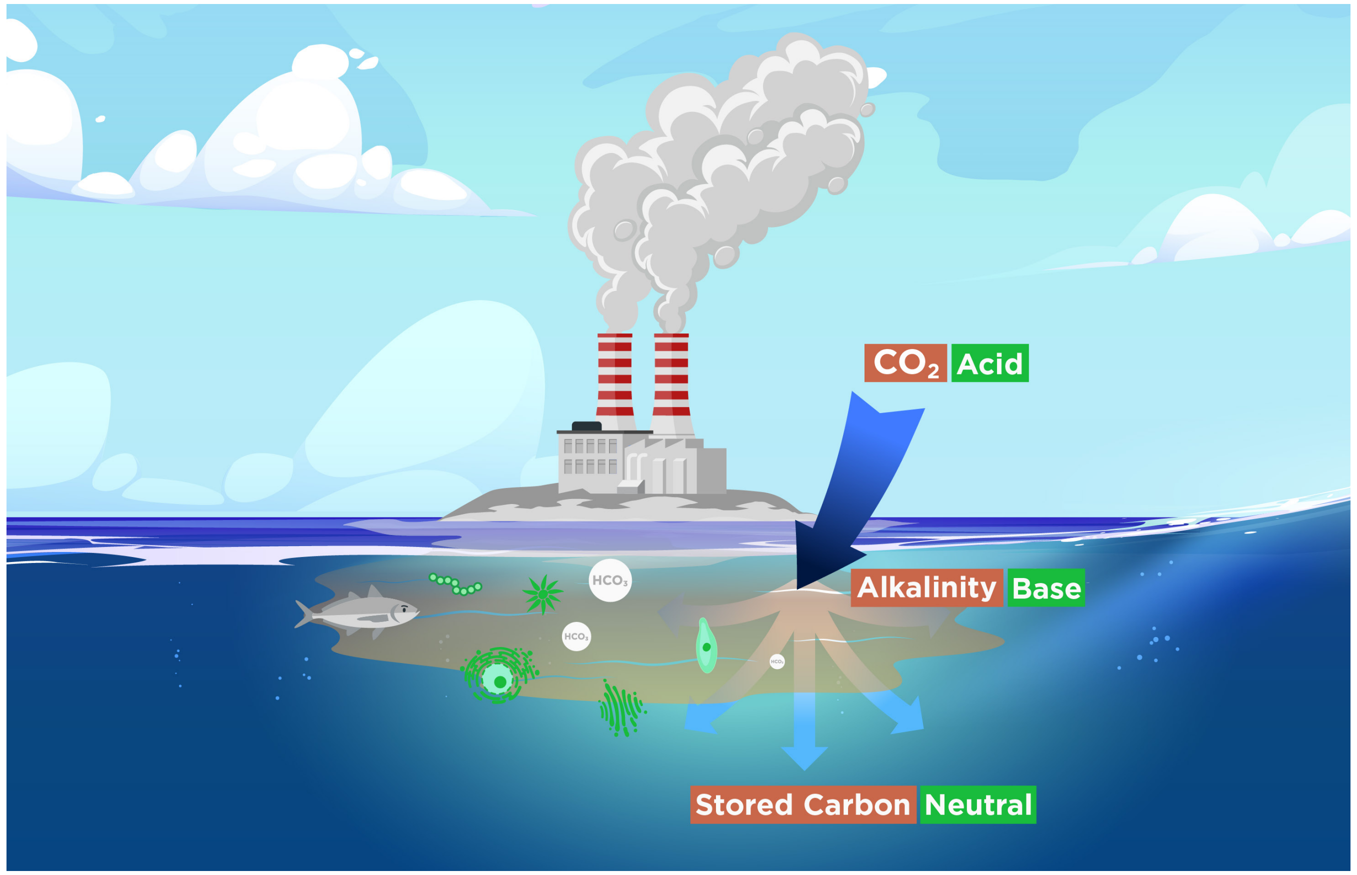
Jessica Oberlander

WE ALL KNOW that climate change is causing many problems including, but not limited to, increased frequency of natural disasters, warmer global temperatures, and a more acidified ocean. Basically, we needed solutions to this problem yesterday. The signing of the Paris Agreement in 2015 was a step forward; one hundred and ninety-six parties from across the globe signed, agreeing to keep the global average increase in temperature below 2 °C. However, in order to meet this goal, not only do we need to reduce carbon emissions, we need to figure out how to remove carbon dioxide (CO_2) from the atmosphere – no small task. While many Negative Emission Technologies (NETs) have been proposed to address the excess CO_2 issue, it is not yet clear how many will be viable in the long term or what kind of impact they could have on the ecosystems in which they are enacted. While understanding the impacts of long term implementation is difficult without real-world application, we can start by finding answers with lab and fieldwork.

WORKING TOWARDS A SOLUTION

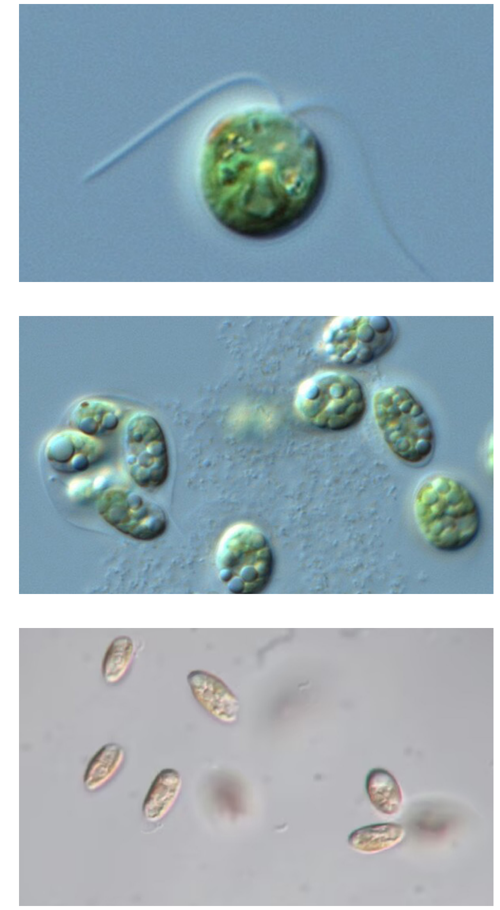
There are a multitude of both land- and ocean-based NETs that have been proposed to remove CO_2 from the atmosphere which have yielded encouraging preliminary results. These include restoration of coastal vegetation, ocean fertilization, artificial downwelling, Ocean Alkalinity Enhancement (OAE), and many more. Ocean Alkalinity Enhancement has the potential to be one of the most effective, as the ocean has already absorbed much of the anthropogenic carbon in the atmosphere and will continue to do so without any human intervention. By mimicking natural weathering processes (see Ruby Yee's article for a more in-depth look at the mechanics of OAE), there is the potential to increase the storage of carbon in the form of bicarbonate.

The basic method of OAE involves adding alkalinity into coastal surface waters through previously established outflow pipes, research vessels, or via beaches. Various types of alkalinity are being investigated for use in OAE; the three most common are sodium hydroxide, magnesium hydroxide, and

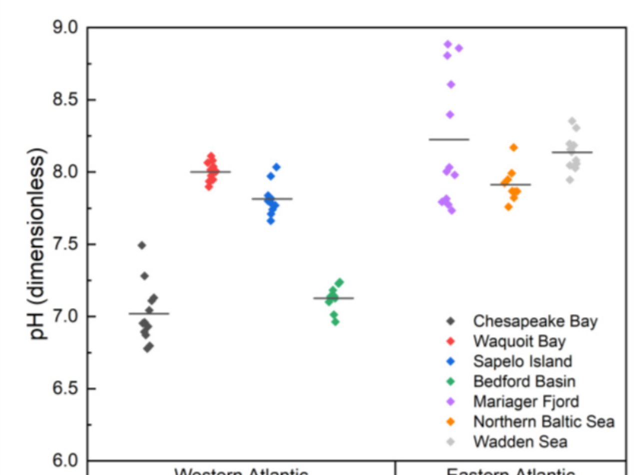


calcium hydroxide, however, research is still ongoing to determine which is the most safe and most effective. These sources of alkalinity can be mixed with seawater to create a “slurry” before being added to the ocean. The additional alkalinity is then able to react with the CO_2, already present in the surface ocean, to form bicarbonate, increasing the ocean’s CO_2 storage capacity and allowing for more CO_2 to enter the surface ocean, continuing the storage cycle (for more information on the effect of CO_2 on the carbon cycle, see Ruby Yee’s article). Bicarbonate, which is the most abundant carbon species in the dissolved inorganic carbon (DIC) pool, is an extremely stable form of carbon. This means that carbon in the form of bicarbonate can be stored in the ocean for timescales of about 100,000 years, or in other words, permanently remove it from the atmosphere. Beyond atmospheric CO_2 reduction, this facet of OAE has the added benefit of reducing ocean acidification and its negative impacts on marine life!

Through the enhancement of the natural carbon storage cycle, it is anticipated that there will be an increase in the total alkalinity present in the area where the addition occurred, as well as a slight increase in pH, which will largely depend on the initial pH of the system and the amount of alkalinity added. However, we need to be careful to make sure that the pH change does not increase too much because this could lead to carbonate becoming the most abundant carbon species instead of bicarbonate. This switch in carbon species could cause calcite precipitation and, eventually, CO_2 to outgas from the ocean, rendering the carbon capture efforts pointless. For these reasons, knowing the initial pH of the system and the change in pH as a result of the added alkalinity is crucial for OAE to be successful. While understanding the changes to the ocean’s chemistry is important, equally important is the potential impacts of elevated alkalinity on marine species, and the best place for us to start examining these impacts is at the base of the food web, with phytoplankton.



Phytoplankton cells pictured under the microscope.
Top: *Chlamydomonas sp.* (CCMP681);
Middle: *Dunaliella tertiolecta* (CCMP1302);
Bottom: *Rhodomonas sp.* (CCMP760).
Images from Bigelow National Center for Marine Algae and Microbiota. www.ncma.bigelow.org

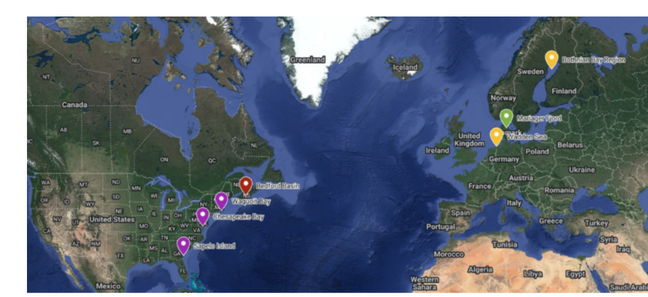


STARTING SMALL TO THINK BIG

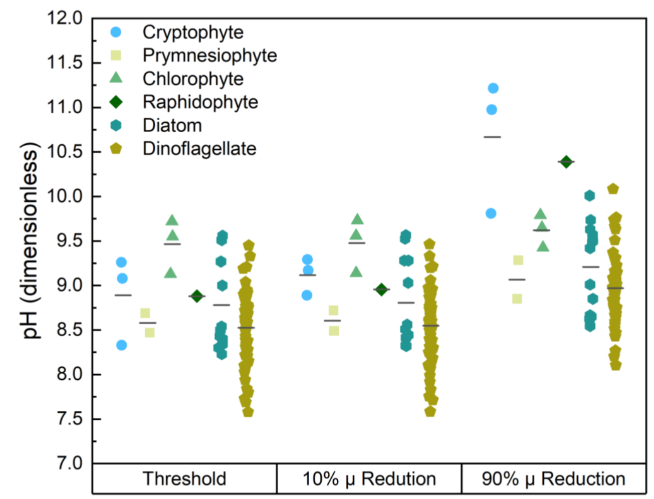
Ranging from 2 – 200 µm in size, about the width of a human hair, phytoplankton make up the base of almost every marine food web and produce approximately 60-80% of the oxygen in the ocean. And just as with larger species, these tiny organisms have been put under environmental stress from the increase in ocean temperature and acidification. Since phytoplankton serve such an important role in the ocean (and to the oxygen we breathe!), investigating how different species will respond to an increase in alkalinity is an important first step in understanding the potential impact of OAE on the marine environment as a whole.

Before diving in to get a look at the potential impact of elevated alkalinity on phytoplankton, we need to take a look at how much pH varies in natural settings to give us an understanding of what they may be able to tolerate. In the Atlantic Ocean, there is a very large range of pH values that occur naturally both between different locations and seasonally in the same location. For example, the seasonal range in pH for Chesapeake Bay is between 6.78 and 7.49, which may not seem like a big difference but keep in mind that pH is on a log scale, so this is close to an order of magnitude difference! However, about 950 km northeast in Waquoit Bay, the pH range is only between 7.89 and 8.11.

This difference could be due to a number of factors, including freshwater input from rivers or even the frequency of rain events. Nonetheless, the variability within and across locations suggests that while some phytoplankton species are likely able to tolerate



Left: Seasonal variations in pH at six locations in the Atlantic Ocean, three on the west coast and three on the east coast.
Top: Map of the sampling locations in 3a. Made with Google Maps



Comparison of the estimate of pH above which there is an impact on growth rates (pHTh), the pH at which there is a 10% reduction in growth rates, and the pH at which there is a 90% reduction in growth rates for a range of taxonomic groups. Each point represents a different species or different growth conditions. The black lines indicate the mean pH values for each group.

the anticipated increase in pH associated with OAE, others potentially may not. This requires further investigation into individual species' responses, but where do we even begin with so many different species? A literature review!

From the literature review, I was able to collect data from various studies that either let the phytoplankton grow undisturbed until they used up all the nutrients or added fresh nutrients on a specific schedule. The phytoplankton were then exposed to different conditions (light intensity, temperature, etc.) to assess the effect of elevated pH on the growth rates of different species of phytoplankton. However, most of the articles I found focused on the slow, seasonal changes in pH and used the method where no fresh nutrients were added, leading to eventual nutrient limitation. For OAE, however, we would expect to see a more sudden change in pH coupled with replenishment of nutrients through the mixing of the water column, for example, by winds or tides, but the existing work is still a useful starting point to begin examining the potential impacts on phytoplankton.

After an extensive literature review, I was able to find data for the response to elevated pH of seventy-two different species of phytoplankton. I then did a lot of data digitization and curve fitting to determine growth rates, but I won't bore you with the details of that here! What's important is understanding the indicator I used to determine when there was a detectable response: threshold pH. This is the pH value where a phytoplankton culture's maximum growth rate began to decline, or more simply, the pH where more phytoplankton died than could survive. Every species has a different threshold because of variations in biochemistry and the differences in their native environment. For OAE to be a feasible NET, the threshold pH values for each species should not exceed a pH of about 8.5 to avoid disrupting the balance in the food webs and keep bicarbonate as the dominant carbon species.

For all of the phytoplankton species I found data on in the literature, the average threshold was above a pH of 8.5. This means that even if we do raise the average pH (8.1) by, for example, 0.3 pH units for an extended period of time, which is an extreme scenario, the majority of phytoplankton will be able to continue growing at the rate they currently do! Some outlier species, mainly the dinoflagellate group, have threshold pH values that fall below even the average pH of the ocean. This could be because the individuals were used to lower pH conditions before the experiment began, such as those in Chesapeake Bay. Cell size and growth rate could also be influences on why dinoflagellates are seemingly more sensitive than the other phytoplankton species. The important thing here, though, is that of the species I investigated, the vast majority appear to experience little to no impact from OAE. This is an important step toward implementation!

THE BIG PICTURE

While there will not be one 'fix all' solution to climate change, OAE has the potential to be a good tool in our toolbox. There is still much more work to be done, including assessing potential impacts on community dynamics (predator/prey interactions, etc.), determining which alkalinity source is the most effective, and looking at impacts on charismatic megafauna such as whales, but in the meantime, there is hope. Ocean Alkalinity Enhancement has the largest CO_2 removal potential, ranging between 14 and 41 gigatons of CO_2 per year, depending on various external factors. That's equivalent to the total global CO_2 emissions in 2021! If we, as scientists, are able to produce enough data to prove that this techno logy is a safe and reliable form of CO_2 removal, then partnered with emissions reductions, we can work towards curbing the impacts of climate change. Then we can build a better future for us all, starting with some of the smallest among us, the phytoplankton.

Jessica, Mikaela, Megan, and Cat preparing for the 2022 mesocosm campaign deployment.
Image credit: Hugh MacIntyre

Jessica collecting carbonate samples from the 2022 mesocosm campaign conducted by the MacIntyre lab.
Image credit: Hugh MacIntyre

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Forecasting Underwater Weather

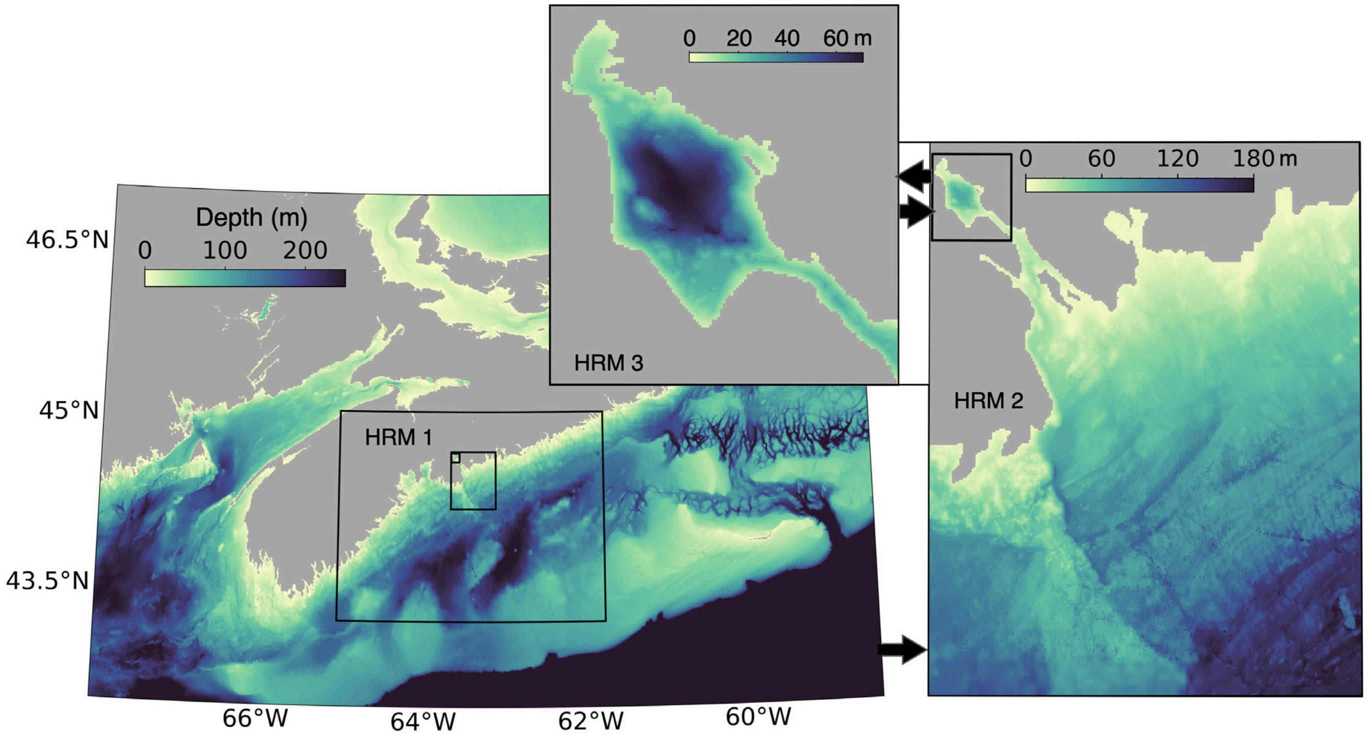
A Model-Guided Exploration of Bedford Basin Intrusion Events

Jacob MacDonald

YOU MIGHT THINK predicting underwater weather is only important for those of us who like to use canned air to spend our time hanging out underwater with our favourite sea creatures. However, forecasting and modelling the ocean is important to everyone, even if you prefer to breathe air above water, as the ocean is a major component of Earth's climate system! Ocean forecasting has become increasingly important in the Bedford Basin, where Planetary Technologies has been pioneering Ocean Alkalinity Enhancement (OAE) – an approach to increase the natural process by which the ocean stores atmospheric carbon dioxide (CO_2) in an effort to help combat climate change.

The ongoing OAE research in the Bedford Basin has a large interdisciplinary footprint in our department of Oceanography (see articles by Ruby Yee and Jessica Oberlander for information on OAE), and I would like to illustrate the importance of coupled physical-biogeochemical models to this research. While the term 'coupled physical-biogeochemical model' might seem daunting at first, it is essentially a way to incorporate many components that represent our current understanding of the ocean. Imagine your math teacher is asking you to solve a complex mathematical equation at the same time that your physics teacher is asking you to calculate the velocity of a rolling ball, your chemistry teacher is asking you to balance a chemical formula, and your biology teacher wants to know about the food chain. That is a lot of information to process and answer all at once! Now imagine having to constantly repeat that for every day in the year, except this time the problems are far more complex and relate to predicting the entire state of the ocean – then you would be a coupled physical-biogeochemical model. Luckily, no one has to do that manually; instead, we get supercomputers to do the job for us! These supercomputers are used to simultaneously solve the many equations that represent our understanding of how the ocean works. By doing this across space and time, we can simulate the many physical and biogeochemical components of the ocean, such as temperature, currents, nutrients, and much more. Therefore, these ocean models are critical for OAE research as they are required to complement measurements and observations.

◀ An aerial view over Halifax Harbour.
Image credit: Noah James Media.



▲ Maps of the Scotian Shelf (HRM1) showing the nested model setup over the Halifax Harbour (HRM2) and Bedford Basin (HRM3). Colour contours show the depth of the ocean bottom (bathymetry). Adapted from Dr. Arnaud Laurent.

The ability for ocean models to meaningfully address knowledge gaps depends on the accuracy of the model and our understanding of what components are important in the model. A regional, coupled physical-biogeochemical model has already been implemented over a section of the Scotian Shelf. The map demonstrates the nested feature of this model, which essentially allows us to zoom in and simulate areas like the Bedford Basin with finer detail. This model is already being used to support the ongoing OAE research and is performing reasonably well at simulating the oceanographic conditions. However, one of the keys to improving the accuracy of this model is understanding the story of intrusion events, a story I have been trying to unravel during my time as an undergraduate student.

Intrusion events are a unique circulation feature characterized by the underwater landscape of the Bedford Basin and the surrounding area. Intrusion events are when seawater from the Scotian Shelf flows laterally through the adjacent Halifax Harbour to reach the Bedford Basin, influencing water properties and representing an important source of oxygen and nutrients. Previous work from our lab group shows that the model performs relatively well at simulating intrusion events; however, we still do not fully understand what causes them.

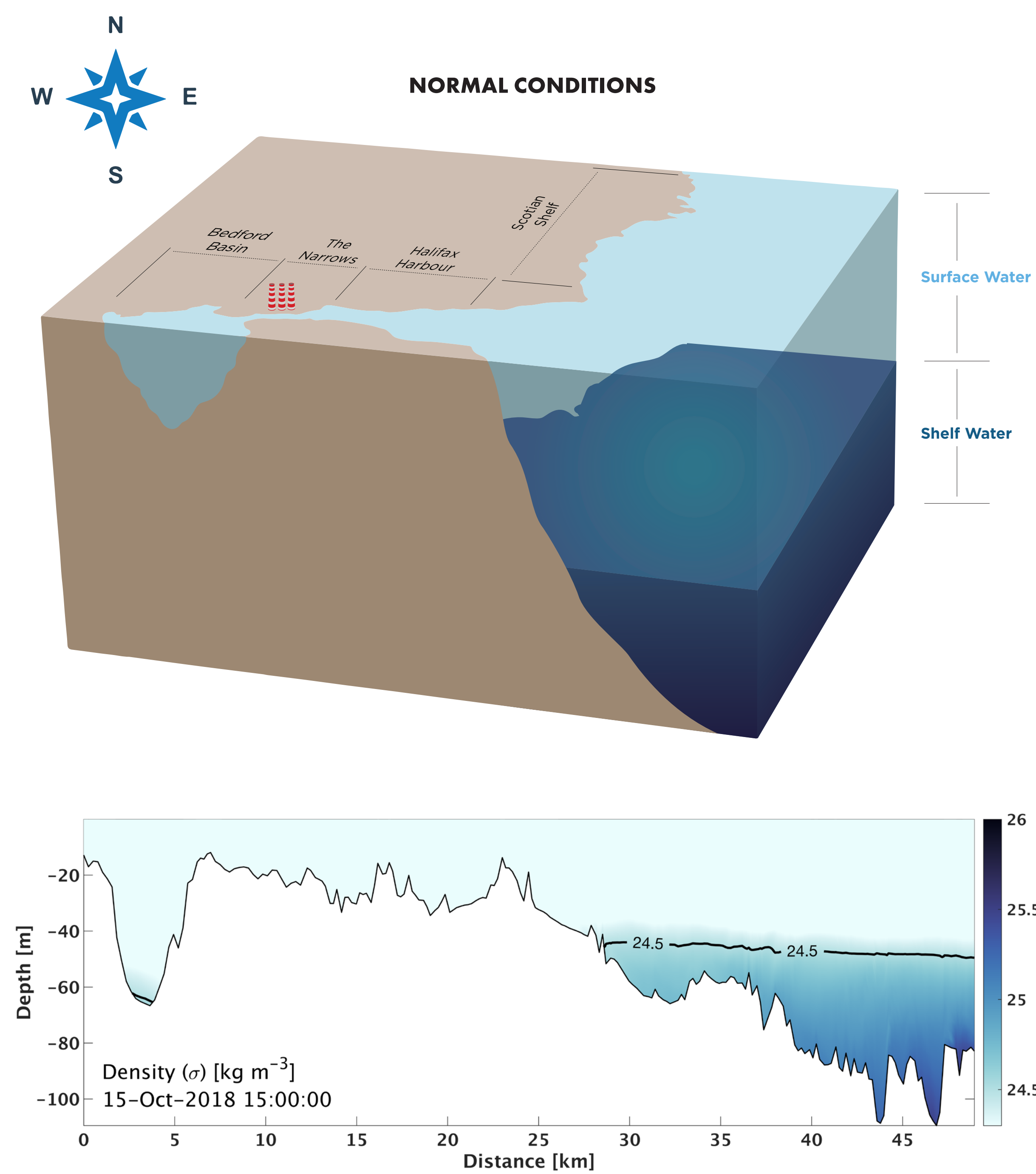
For my undergraduate research, I was interested in finding out what conditions (or combination of conditions) cause water from the Scotian Shelf to travel all the way into the Bedford Basin during an intrusion event. To do this, I first needed to identify intrusion events in our model. I used a model simulation known as a hindcast, which retroactively simulated the past twenty years (2003-2023) of the Bedford Basin and surrounding area. This hindcast simulation allowed me to

explore and develop a better understanding of intrusion events and how they impact the dynamics of the Bedford Basin. Throughout the entire hindcast, intrusion events in Bedford Basin typically occurred zero to two times a year and were consistently identified by an increase in salinity. This is because water intruding from the Scotian Shelf is always saltier than water in the Bedford Basin, which is fed freshwater from the Sackville River. After identifying intrusion events across the twenty years of the model hindcast, one event in 2018 that was simulated well compared to observations was selected for an in-depth analysis.

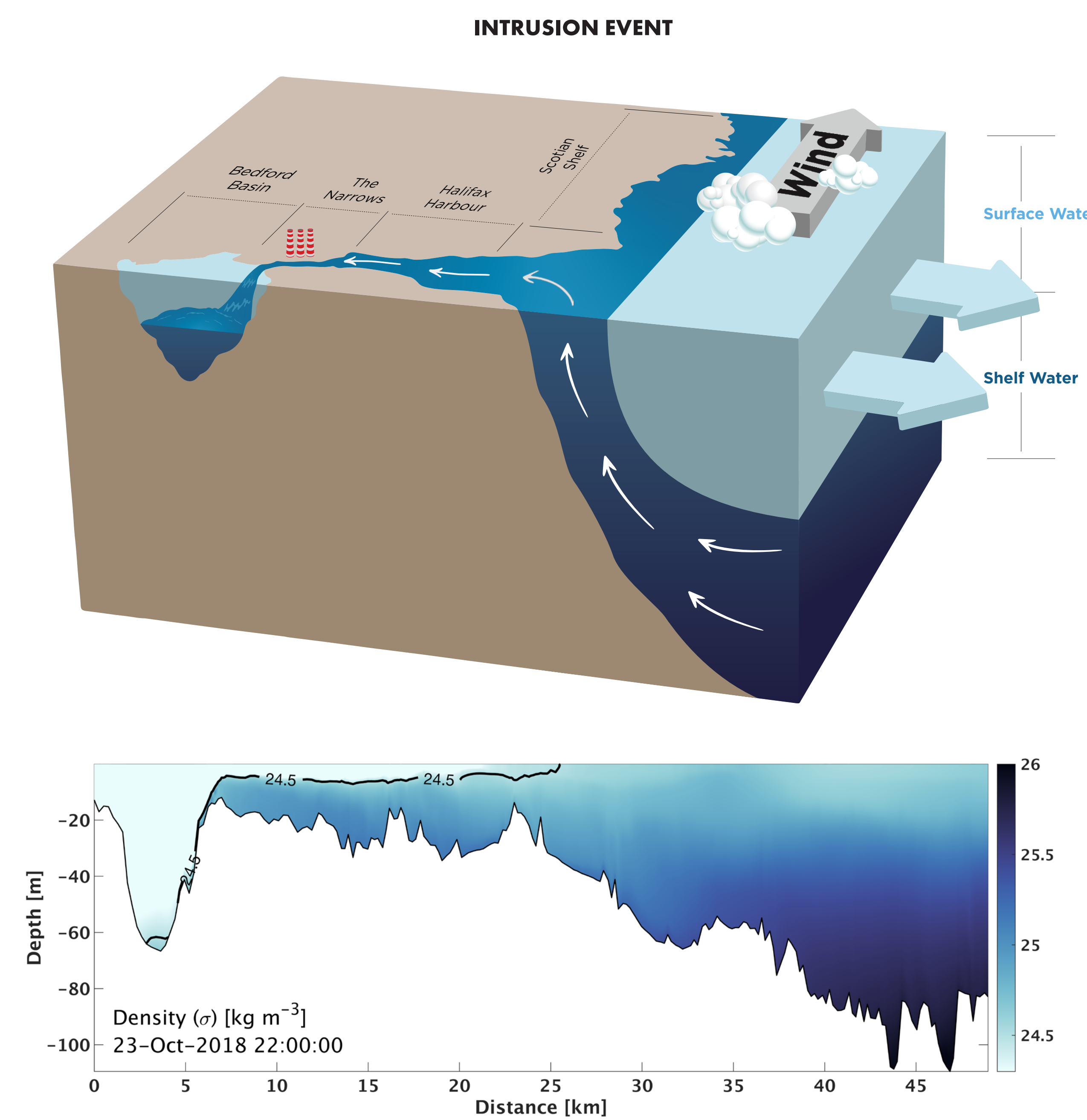
Using the intrusion simulated in 2018 as a case study, I was able to identify four unique stages of an intrusion event. Evaluating oceanographic conditions, such as the winds and water velocities during these stages, helped provide a mechanistic explanation of what caused the simulated intrusion in 2018. Before the intrusion, under normal conditions, the shelf water is saltier (and often colder) than waters at the surface. Therefore, the shelf water is heavier, or more dense, so it remains below the surface waters (see 'normal conditions' schematic on next page). However, during stage one of the intrusion, the “Shelf Setup Stage”, there was a large spike in southwestern winds, blowing parallel to the coast over the Scotian Shelf (represented by the wind arrow in 'intrusion event' schematic on next page). Because of Earth’s rotation, the upper surface water layer does not actually move in the same direction as the wind; instead, it will experience a net movement that is 90 degrees to the right of the wind (in the Northern Hemisphere). This is known as Ekman transport, and it means that the southwestern wind across the Nova Scotia coastline pushes the surface water away from shore. This causes coastal upwelling because the dense shelf water then travels shoreward as it must move up (upwell) from below to replace the surface water that is moving away from the coast (see shelf water movement in 'intrusion event' schematic on next page). Therefore, coastal upwelling drives the movement of the shelf water towards the shore, causing it to eventually push into the Halifax Harbour during stage 2, the “Harbour Intrusion Stage”. The dense, intruding shelf water continues pushing shoreward until it is at the end of The Narrows, right on the edge of the Bedford Basin. Now, in stage 3, “Bedford Basin Intrusion”, the tides take over and regulate the flow as the intrusion only enters the Basin on the incoming tide (flood tide). Because of its higher density, the shelf water sinks to the bottom of the Basin (see Bedford Basin in 'intrusion event' schematic on next page). This continued until the prevailing wind direction changed from southwest, triggering stage 4, “Receding”, as the intrusion stops and recedes back to the Scotian Shelf.

Putting it all together, southwestern winds were the main mechanism setting up the simulated intrusion event, while the tides regulated the flow into the Bedford Basin. This was only the case for one simulated event, and the situation could be different for others. For instance, the four stages do not always occur; sometimes, intruding water will only make it into the Halifax Harbour (Harbour Intrusion Stage) and not all the way to the Bedford Basin. The amount of intruding shelf water that does make it to the Basin can also vary. To truly improve the accuracy of our model, we want to simulate and predict all intrusion events correctly. Therefore, the mechanism hypothesized for the 2018 intrusion should be tested for all simulated and observed intrusion events to strengthen our understanding. Doing so will help us further improve our model and its “underwater weather” predictions. This remains an important feat, even if you prefer to breathe air above water, as the model continues to be relied upon in the ongoing effort to help mitigate climate change through the OAE work in the Bedford Basin.

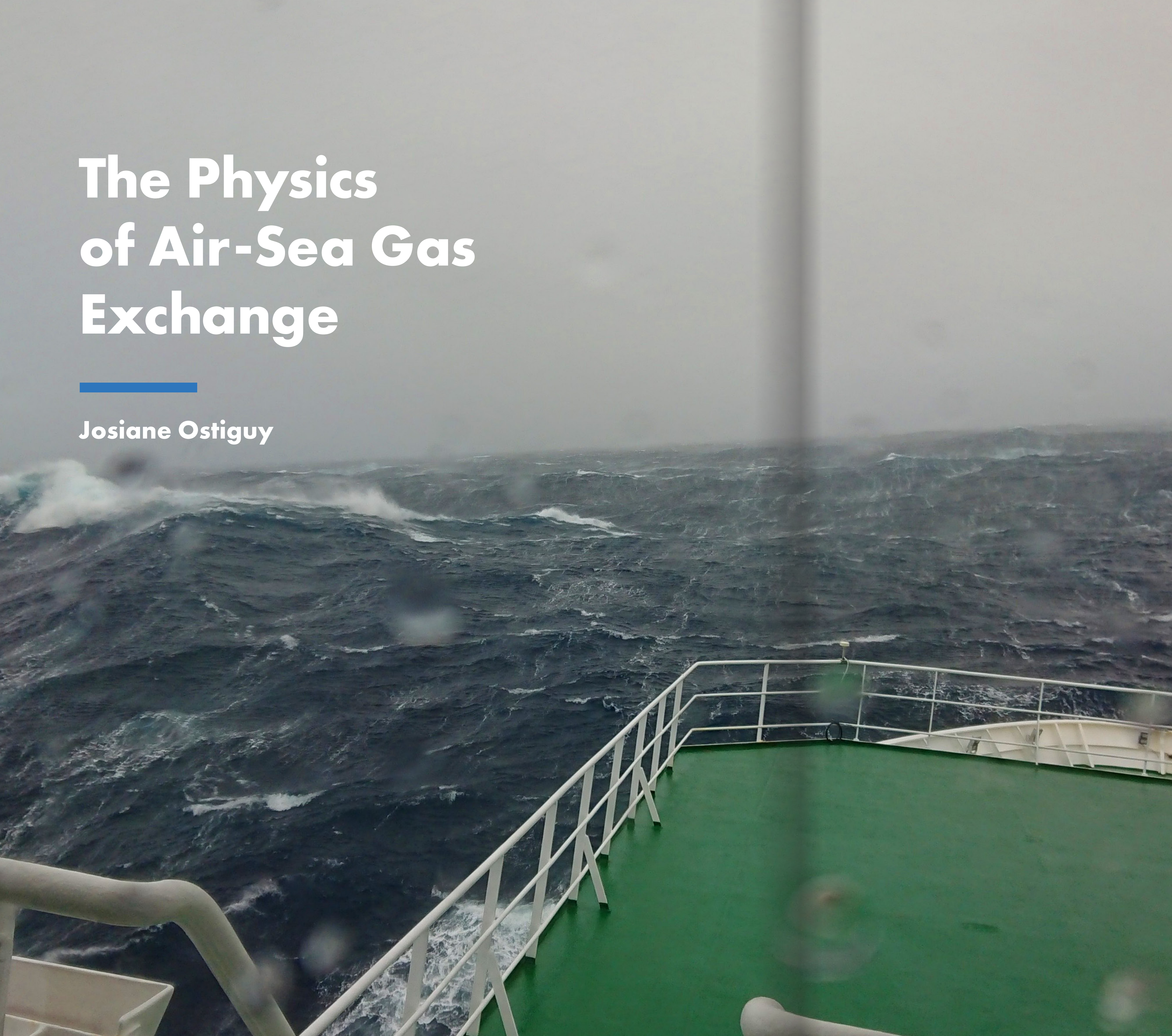
Scan to watch a video showing the simulation of the 2018 intrusion event.



▲ Normal sea state before an intrusion event, shown schematically and with a snapshot of density from the model along the Bedford Basin to the Scotian Shelf. The denser (heavier) shelf water rests below the lighter surface water.



▲ Sea state during an intrusion event, shown schematically and with a snapshot of density along the Bedford Basin to the Scotian Shelf from the simulated intrusion event in 2018. The winds were predominantly from the southwest during the intrusion and are hypothesized to drive the shoreward movement of the dense shelf water leading to the intrusion, as depicted in the schematic.



The Physics of Air-Sea Gas Exchange

Josiane Ostiguy

THE CONSTANT INTERACTION between the ocean and the atmosphere is fundamental in shaping Earth's climate. While some of these interactions are easy to observe, like waves being generated on a windy day or the feel of a cool ocean breeze, others can't be directly seen but are equally important. One such unseen process is the exchange of gases like carbon dioxide (CO_2) between the air and the water, which happens when there's a difference in CO_2 concentration between what's dissolved in the ocean and what's in the atmosphere. The rate at which this exchange occurs is determined by the physics of the ocean's topmost layer.

At the ocean's surface lies a thin boundary layer, typically no more than a few millimeters deep. Within this thin layer, the forces of friction and viscosity dominate. Here, the movement of CO_2 is driven by molecular diffusion, a process where molecules randomly move from an area of higher concentration to an area of lower concentration. Because molecular diffusion is an incredibly slow process, movement across this surface boundary layer is the rate-limiting step for gas exchange. However, turbulence in the water can disrupt this layer, making it thinner and shortening the path CO_2 needs to diffuse across. Consequently, high levels of turbulence lead to a faster rate of gas exchange.

WHY DOES GAS TRANSFER RATE MATTER?

The exchange of CO_2 between the atmosphere and the ocean directly influences the global carbon cycle because the ocean acts as a vast reservoir, storing a significant portion of anthropogenic CO_2 emissions. This is a crucial consideration for carbon capture methods like Ocean Alkalinity Enhancement (OAE), which aim to draw down and store CO_2 in the ocean. Accurate estimates of CO_2 drawdown are essential to determine how efficient these climate interventions can be.

Alkalinity additions are likely to be in coastal regions where access is feasible and existing infrastructure can be used to release alkalinity into the ocean. After a coastal alkalinity addition, CO_2 could be drawn down near the addition site or further away depending on how the alkalinity enhanced water disperses. The physical processes that drive gas exchange in coastal regions and estuaries, however, are typically different from those in the open ocean. This means that the conditions under which gas transfer will occur will be vast and we need to understand how accurate gas transfer calculations are under diverse conditions.

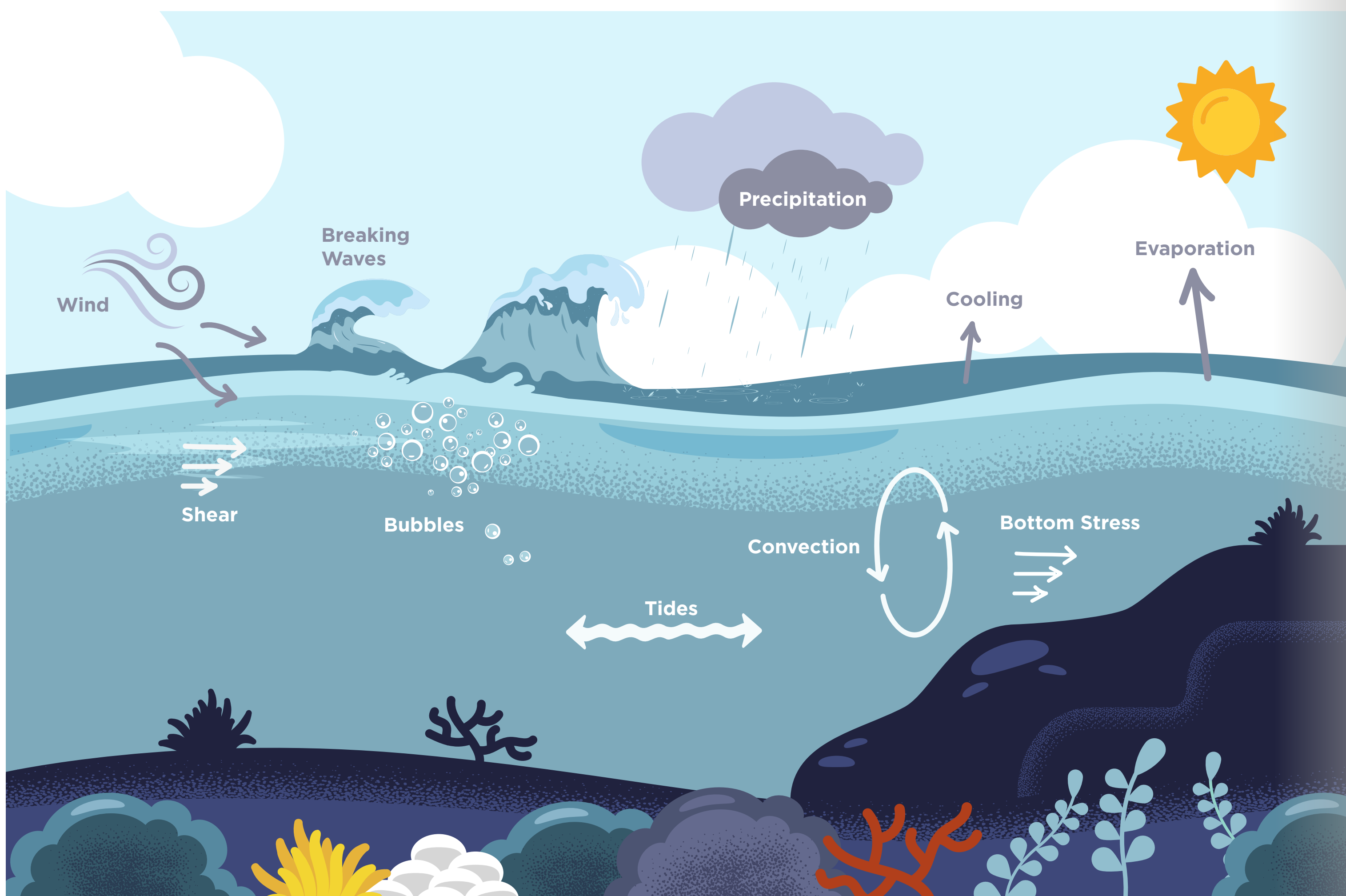
THE CHALLENGES OF CURRENT TECHNIQUES

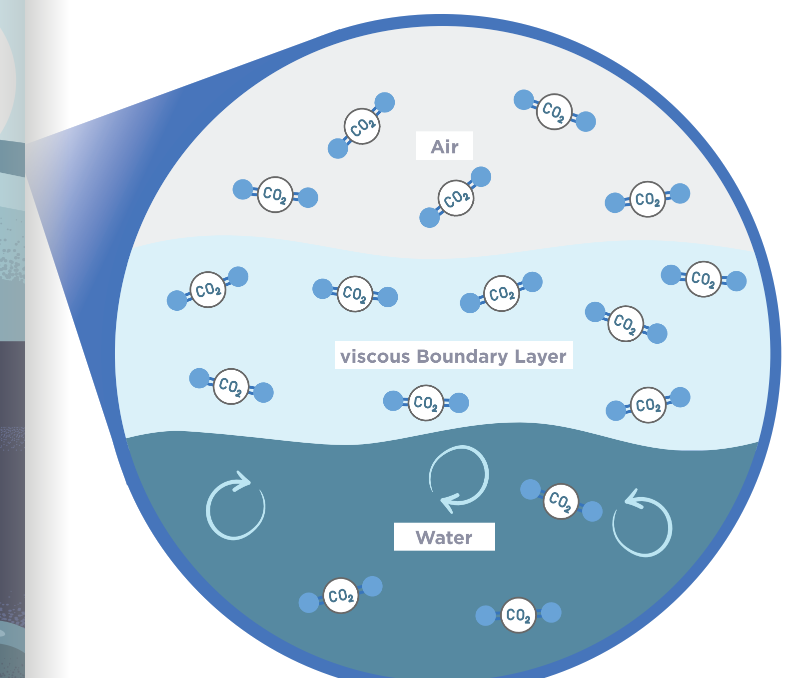
Directly measuring gas flux between the ocean and atmosphere is a significant challenge. It requires highly precise instruments and very specific environmental conditions to work effectively. For this reason, much effort has focused on relating the gas exchange rate to other, more easily measured and widely available quantities.

The most common approach involves using wind speed, as concurrent measurements of wind speed and gas flux have shown that the gas transfer rate is roughly proportional to the square of the wind speed. While this method works well for estimating gas transfer at wind speeds between 20 and 50 km / hr, its accuracy is reduced at lower and higher wind speeds.

Furthermore, this method assumes that turbulence in the surface water is solely driven by wind. This makes it less accurate in environments where other physical processes play a significant role in driving turbulence and gas exchange. For example, surface turbulence can be set by atmospheric factors like precipitation and air temperature, as well as oceanic factors such as breaking

▼ Schematic of physical processes that are important for air-sea gas exchange, with a closer view of the air-sea boundary where gas exchange occurs.





waves, water current speed, and the interaction of currents with the seabed in shallower regions. Breaking waves can also inject bubbles into the water, leading to more gas exchange than wind speed alone would predict. Given these limitations of the wind speed approach, we need to develop more accurate methods for estimating gas exchange rates that account for these additional drivers of surface turbulence.

PHYSICS IS THE KEY!

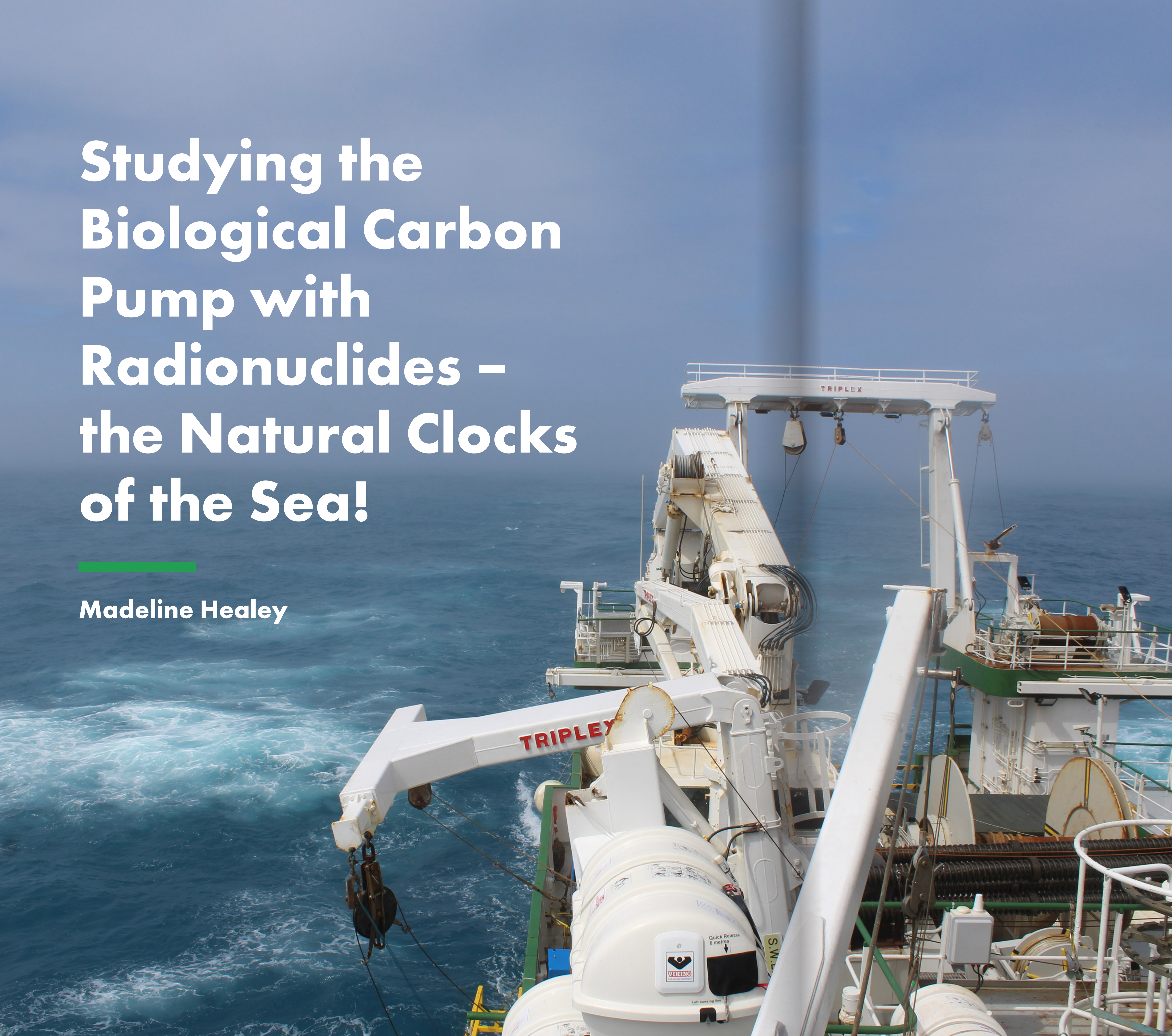
I study turbulent mixing and how it relates to the physics of air-sea gas exchange. My research takes a two-pronged approach to this problem; understanding the physical mechanisms behind gas exchange and testing our understanding in varied environments.

Turbulence in the ocean is not an easy thing to measure and relies on the use of incredibly sensitive probes – about as fragile as a potato chip – and are highly susceptible to any vibrations in the surrounding environment. Therefore, idealized simulations are invaluable tools for gaining insight into the complex interplay of physical processes that drive gas exchange. They provide a controlled environment where we can manipulate individual physical processes, allowing us to determine how each contributes to surface turbulence and, consequently, gas transfer. These models offer a significant advantage over field measurements by enabling rapid comparison of different gas transfer rate calculation methods (e.g., wind speed vs. surface turbulence - based) across a vast range of conditions. Further, we can also compare turbulence and wind speed measurements to simulations set up with matching environmental conditions, which helps us interpret the data and understand the dominant processes driving gas exchange.

To deepen our understanding of gas exchange, we measure turbulence in conditions outside the range that is known to agree well with the wind - speed based approach. My research involves two vastly different environments: the storm - swept Labrador Sea in winter and the more sheltered Bedford Basin estuary. In the Labrador Sea, the turbulence measurements were made in high - energy conditions, under severe storms with wind speeds sometimes reaching 100 km / hr. These measurements were part of a collaborative effort that also included a host of other concurrent observations to better understand bubble - mediated gas exchange in this region.

In stark contrast, the Bedford Basin is an estuary where the processes determining surface turbulence are likely very different. In parts of the estuary the water is so shallow that the seafloor interacts with strong tidal currents, creating turbulence that could reach all the way to the surface. The estuary is also enclosed by the coastline so there's less room for wind to build the large waves you'd see in the open ocean. By understanding these diverse processes and their contribution to gas exchange across various seasons, we can assess the accuracy of current CO_2 exchange rates for these two very different environments. This work could also lead to the development of a new, more accurate estimate of the gas exchange exchange rate tailored to these unique environments.

Ultimately, my goal is to gain a deeper understanding of the physical drivers of gas exchange in various environments and to improve the existing methods used to calculate the gas exchange rate. This will, in turn, lead to more precise estimates of CO_2 exchange and drawdown, making the efficiency estimates for Ocean Alkalinity Enhancement a more reliable tool in our climate mitigation efforts.



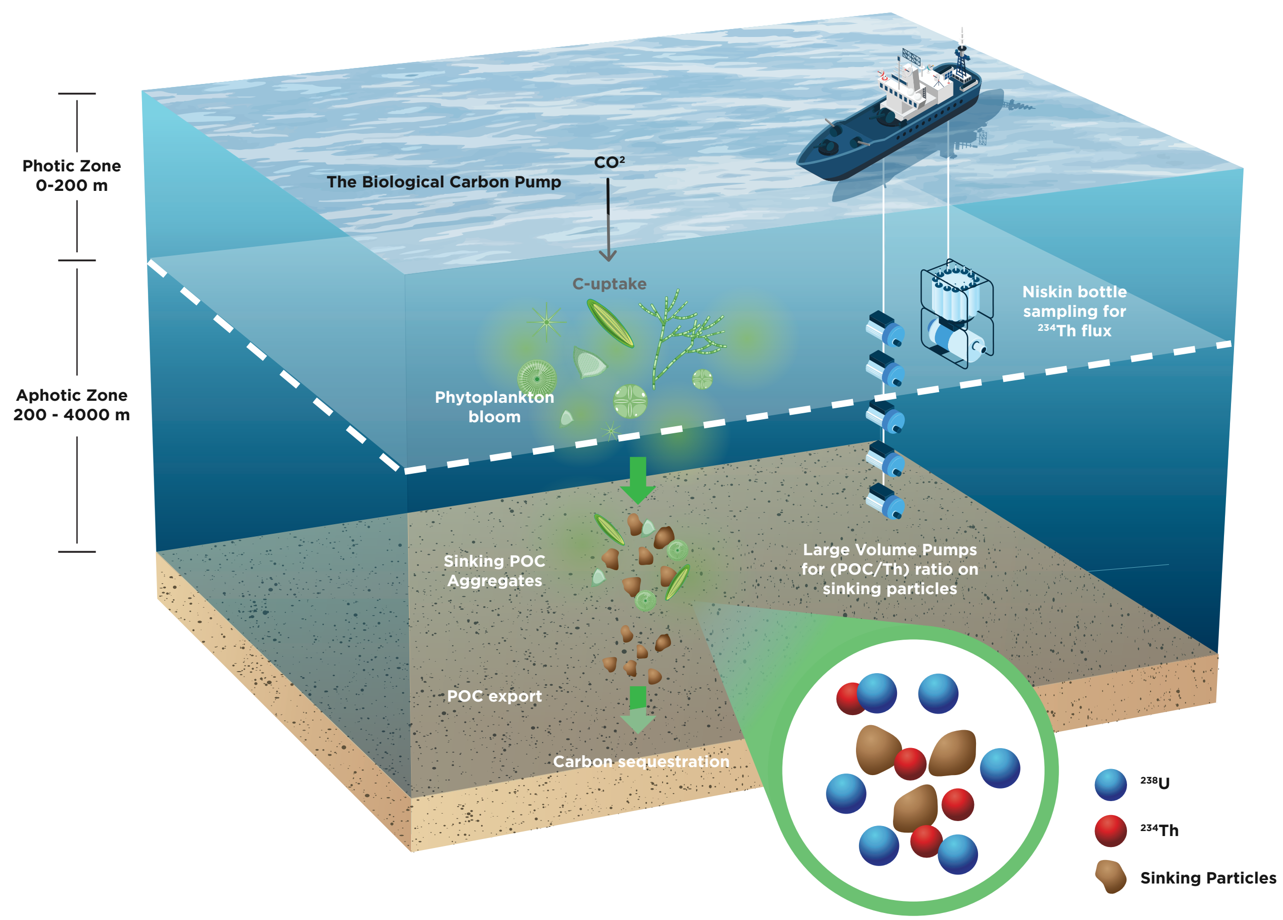
Studying the Biological Carbon Pump with Radionuclides – the Natural Clocks of the Sea!

Madeline Healey

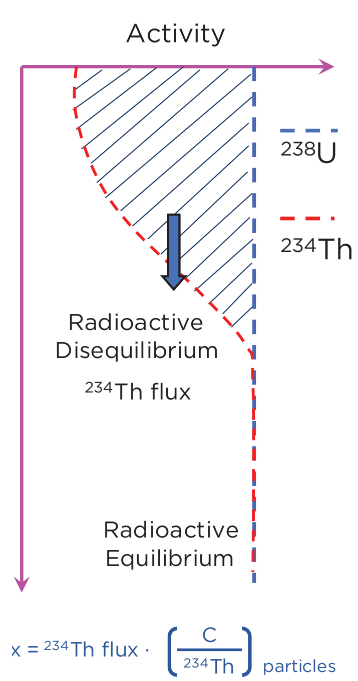
BENEATH THE OCEAN'S SURFACE, natural clocks crafted from radioactive decay tick away, mirroring the passage of time we experience on land. Just as the steady rhythm of seconds, days, and years shapes our individual lives, radioactive isotopes mark the relentless flow of time in the marine world. These isotopes tick away silently, decaying at a predictable rate and their gradual decay offers a fascinating glimpse into many marine processes, including sediment accumulation, water mass tracking, insight into nutrient cycles, and in my case, better understanding particle export as it relates to the biological carbon pump (BCP).

The biological carbon pump begins in the sunlit surface ocean, where phytoplankton take up atmospheric carbon dioxide (CO_2) during photosynthesis, and transform it into particulate organic carbon (POC). A majority of this carbon remains in the surface ocean where it is recycled by bacteria and can easily leak back into the atmosphere. To be removed from the atmosphere, carbon must sink to the deep ocean and ideally, be buried in seafloor sediments. But only a small fraction of this carbon made in the surface ocean takes this journey. To understand this pathway, we measure the sinking flux of POC, transported mainly by large, carbon-rich particles including zooplankton fecal pellets, detritus, and phytoplankton aggregates. These particles are heavy enough to sink out of the upper ocean and be exported to the deep ocean where it can be remineralized back into CO_2 or buried in sediments and locked away for thousands to millions of years. The biological carbon pump has an important role in climate regulation, for it has been projected that without it, atmospheric CO_2 would be approximately 50% higher than it is today.

My project seeks to enhance our understanding of the ocean's biological carbon pump through observations taken in the Labrador Sea, a semi-enclosed basin between Canada and Greenland. Being one of the few global sites for deep water formation, the Labrador Sea is a region of intense uptake of CO_2 and has been found to have a strong BCP. An excellent tool to study particle flux and quantify metrics that describe the biological carbon pump are radioactive isotopes. Put simply, radioactive isotopes are types of atoms that are unstable and will undergo radioactive decay by releasing energy over time.



▲ An overview of the Biological Carbon Pump and the ^{234}Th/^{238}U disequilibrium methods deployed at sea to capture the sinking flux of particles.



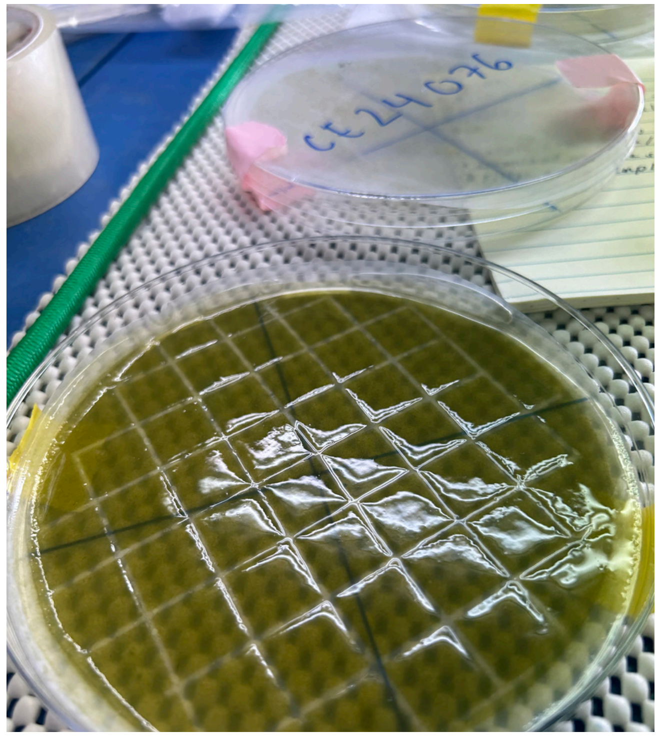
Just as each tick of a clock represents a passing second, the half-life of an isotope represents the time it will take for half of the radioisotope to decay. You may be familiar with radiocarbon dating, which uses the slow decay of carbon isotopes to determine the ages of mummies or mammoths. In the ocean, we use the same principle of radioactive decay, but with much shorter-lived isotopes to study particle fluxes. This consistent decay rhythm allows us to date and track marine processes. For my work, we selected the various isotopes of thorium to trace POC export in the ocean. The isotopes of thorium that we study are naturally occurring in the marine environment, and decay from their 'parent isotope' uranium-238 (^{238}U). Thorium is very insoluble in seawater and thus has a very low concentration. This small amount of thorium in the water is readily adsorbed or "scavenged" on to particulate matter, meaning that thorium quickly attaches to sinking particles and is removed from the water column. Thorium's insolubility and its well-characterized production from the decay of ^{238}U make

Team Thorium aboard the R.V. Celtic Explorer in spring 2022. Dr. Munsta Roca Marti (left), Dr. Stephanie Kienast (middle), Madeline Healey (right).

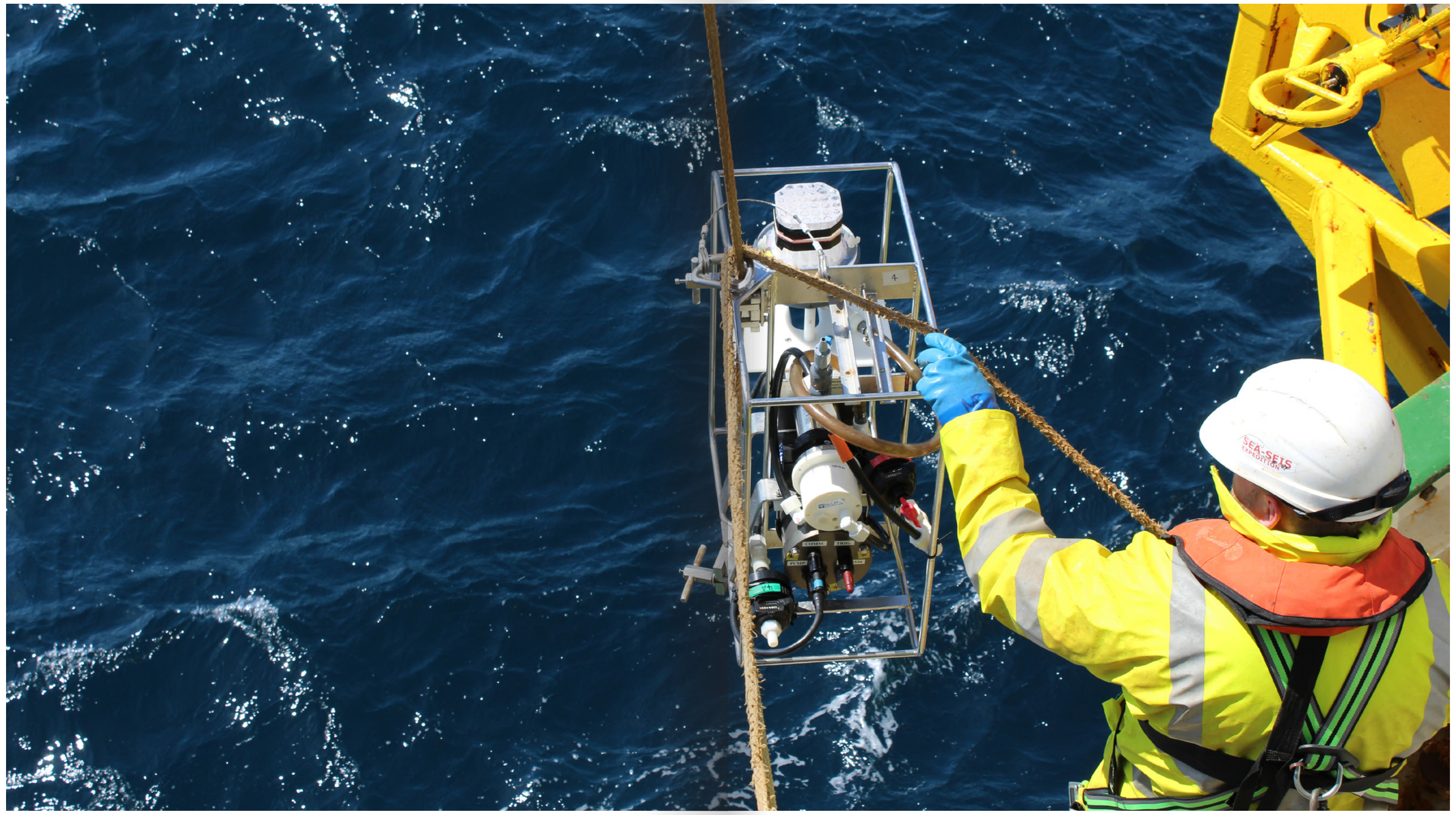
it an effective stopwatch in the ocean. By comparing the extent of thorium removal to that of ^{238}U, we can take advantage of thorium's short half-life to focus on particle export over weeks to months. In this way, thorium acts as a natural stopwatch: its predictable decay rhythm sets the timeframe, while the deficit relative to uranium reveals the amount of material being exported. Together, this allows us to quantify the flux of sinking particles and evaluate how efficiently carbon is transferred out of the surface ocean.

I primarily work on thorium-234 (^{234}Th), a shorter-lived isotope of thorium, with a half-life of only 24 days. Due to its short half-life, ^{234}Th is an ideal clock to trace particle export in the upper water column, where most particulate matter occurs, and the greatest amount of POC is found. While at sea, we measure total ^{234}Th in seawater and collect sinking particles with large ^{234}Th volume pumps that we deploy between 0–500 m. By combining these measurements, we can calculate how much carbon is leaving the surface ocean.

By studying particle export using ^{234}Th, we are unravelling unknowns regarding the BCP. Significant uncertainties in the magnitude of biologically driven carbon uptake and storage in the ocean stem from our incomplete understanding of the various pathways through which POC is transported via the biological carbon pump from surface waters to the deep ocean. For example, in our 2022 field campaign to the Labrador Sea, we cruised into a massive bloom of a specific phytoplankton group called *Phaeocystis pouchetti*. Little is known about how *Phaeocystis* impacts export. Some studies have suggested that *Phaeocystis* colonies might be a major contributor to carbon flux to depth, while others have shown that *Phaeocystis* cell carbon does not contribute significantly to vertical carbon export. In our study, contrary to the idea that more biomass would mean more carbon export, our data suggest that the community structure of a *Phaeocystis* bloom may lead to lower export, and a weaker BCP. This could in part be due to their ecophysiology, whereby their gel-like colonies are remineralized quickly in the upper water column



A filter taken from a large volume pump deployed in the Labrador Sea that is covered in *Phaeocystis* biomass.



Large volume pumps (LVPs) ready to be deployed at sea. These LVP's are deployed to depths between 0 – 500 m and pump hundreds of litres of seawater to sample marine particles that are measured for particulate organic carbon (POC) and thorium-234 (^{234}Th)

and are not dense enough to sink to deeper depths. Climate change is predicted to rapidly influence algal communities, and whether or not *Phaeocystis* will become more prominent with a warming climate is still unclear.

Time has ticked away since you started reading this article. Next time you look at your watch, consider thorium-234, nature's own timekeeper, ticking away in the ocean's depths. This remarkable radionuclide serves as a precise clock, transforming our understanding of the BCP and particle export processes crucial for carbon sequestration and climate regulation. By unraveling these marine mysteries, ^{234}Th not only marks time but also paves the way for a deeper understanding of the ocean's role in the global carbon cycle, guiding us toward more effective environmental policies and strategies.

Seawater samples being filtered onboard to quantify total ^{234}Th, capturing both dissolved and particulate fractions. Total ^{234}Th measurements are essential for constraining thorium deficits and calculating particle export fluxes

Deploying the large volume pumps into the Labrador Sea.

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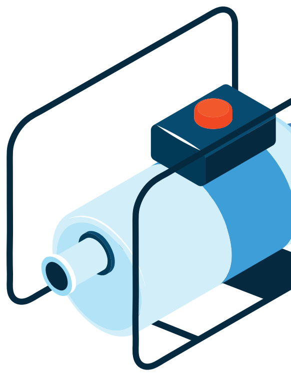


An ocean mixer under the ice

Lina Rotermund

THE CANADIAN ARCTIC ARCHIPELAGO (CAA) is a breathtaking, dynamic, and complex region, which has been home to indigenous peoples for thousands of years and inspired centuries of exploration in the quest for the fabled Northwest Passage. My research focuses on Barrow Strait, a part of this famous passage, and within the Tallurutiup Imanga National Marine Conservation Area, established in 2019. I am investigating physical ocean processes that modify and mix the waters in this area.

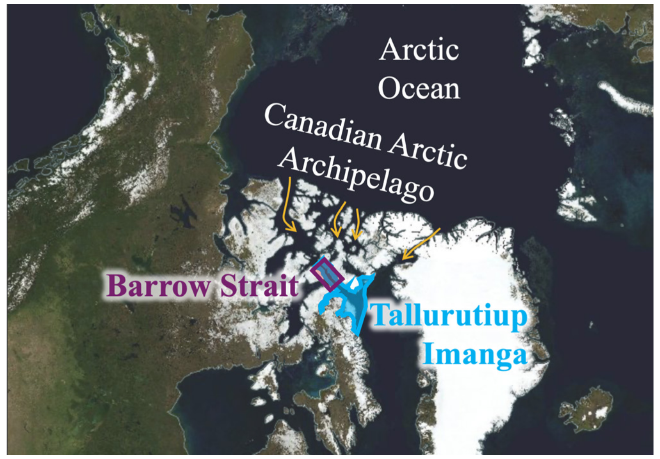
THE IMPORTANCE OF THE CANADIAN ARCTIC ARCHIPELAGO & BARROW STRAIT

Tallurutiup Imanga National Marine Conservation Area is rich in culture and wildlife and has great ecological and social significance for the eastern CAA. A recurring annual polynya – an area of reduced ice cover or open water surrounded by extensive ice cover – is one reason for the notable biodiversity in Lancaster Sound, just west of Barrow Strait. Polynyas can be likened to an oasis for polar regions, with enhanced biological production attracting an abundance of marine life including fish, seals, walrus, narwhal, bowhead and beluga whale, polar bears, millions of migratory seabirds, and more.

The significance of Barrow Strait and the CAA extends beyond local implications. The CAA is one of two major oceanic outflow gateways between the Arctic and Atlantic Oceans and Barrow Strait transports 30–50% of the total CAA outflow. These Arctic outflow waters play a role in regulating global ocean circulation and climate. As a result, the drastic changes we have been observing in the Arctic – rapid warming and substantial sea ice loss – have far reaching impacts well beyond their immediate vicinity.

OBSERVATIONS

A team of research scientists within the Department of Fisheries and Oceans Canada at the Bedford Institute of Oceanography spearheaded a mission to monitor the ocean in Barrow Strait. Between 1998 and 2011, they measured water column properties at four locations across the 60 km wide strait. This includes 13-years of observations of ocean and ice velocities, temperature and salinity at fixed depths, two years of daily temperature and salinity profiles, and multiple



▲ The location of Barrow Strait in Canada's Arctic.

years of sea ice thickness. This is an incredible and valuable data set! Arctic environments are remote and extremely challenging to collect observations in, making this monitoring program really something special.

Fast forward to 2017. After a six-year hiatus, the successors to the original team reignited portions of the initial mooring-array program! Once again, every year or two, during the Arctic summer, when the ocean is mostly ice free, a team flies to Resolute Bay, the second most northerly Inuit community in the Canadian Arctic tundra, and hops on a Coast Guard ship. From the ship they recover and redeploy moorings, collecting data that will continue to grow this vast time series.

In 2022, I had the privilege to go north alongside the group and contribute to this project—and yes, I did see polar bears (from a comfortable distance). My job was to measure the water properties along a transect spanning the strait. We lowered an instrument equipped with salinity, temperature, depth, oxygen and pH sensors into the water down to the seafloor. Moreover, we also collected water samples at various depths using niskin bottles. These measurements, which had not been completed since 2010, give a summertime snapshot across the strait, complementing the long time series.

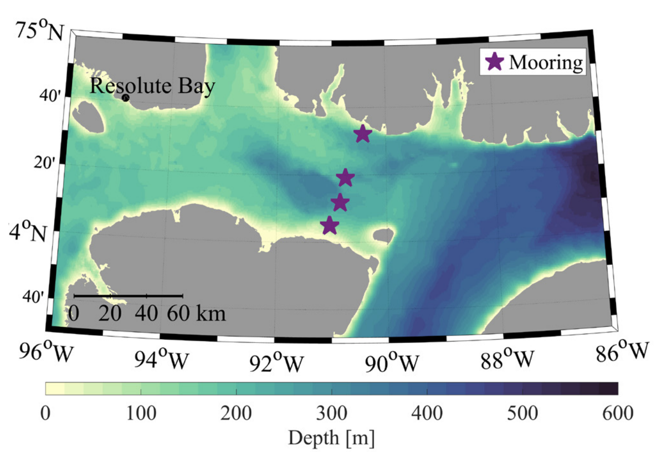
Thanks to all of these efforts, I can now use a data set spanning two decades to investigate the processes that govern water mass modification and mixing in the CAA and Barrow Strait.

LAYERS IN THE OCEAN: WATER MASS MODIFICATION & MIXING

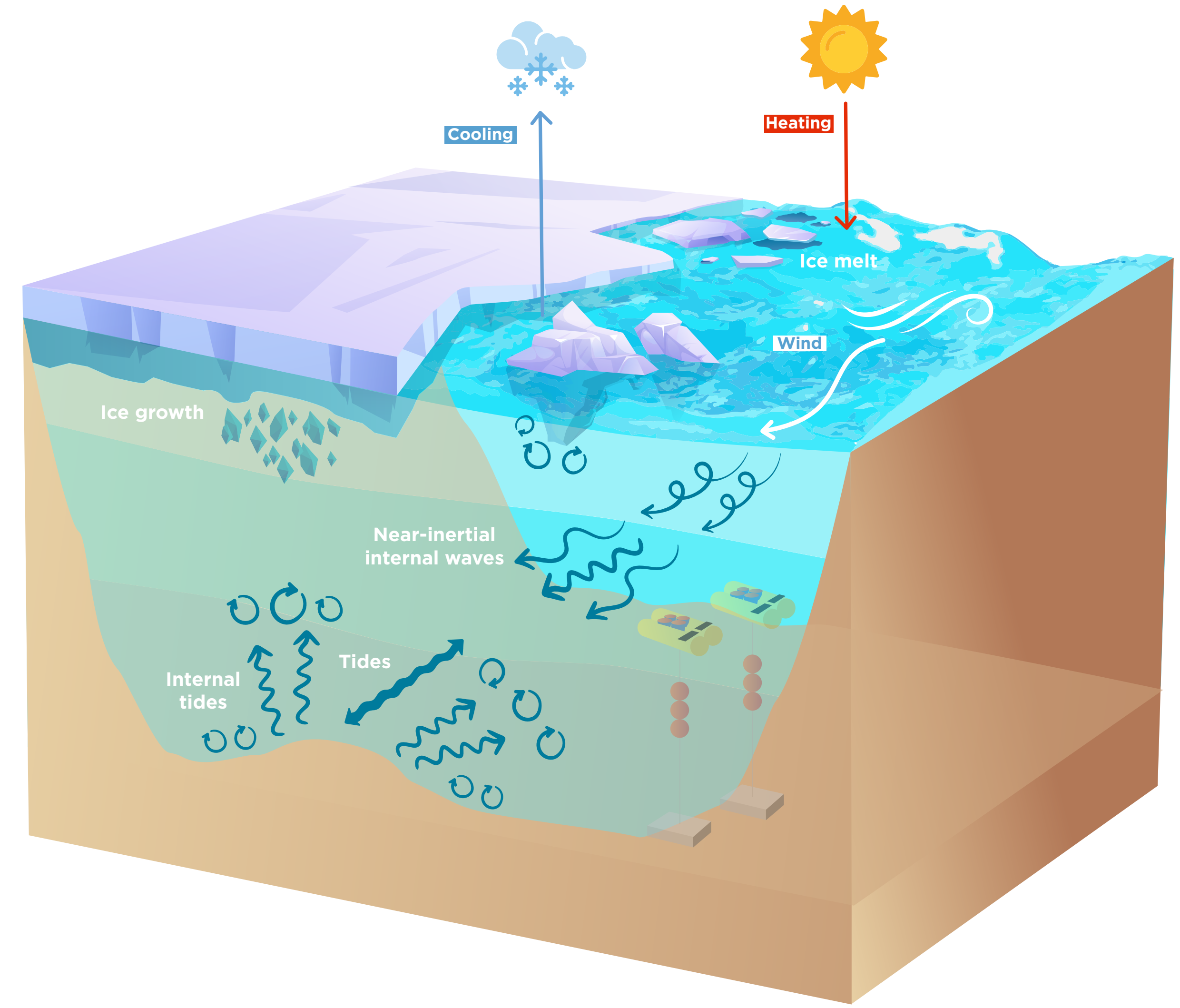
Most of us think of the ocean as a big, well mixed body of water but the ocean is actually stratified meaning that each ocean layer has different physical water properties that may hinder mixing. The upper layer, in contact with the atmosphere, is usually well mixed. The depth of this mixed layer can range between a few meters to tens or hundreds of meters depending on the season and location. Underneath this mixed layer, density increases with depth. Water density depends on temperature and salinity, with warmer water being less dense than colder, and fresher water being less dense than salty.

Arctic waters have a limited range in temperature – they are always relatively cold (-1.8 to 5 °C) – and so differences in salinity dominate variations in density. In these environments, comparatively salty, warmer water sits below fresher, colder water. My work seeks to uncover how these water masses are modified and mixed as these processes play a key role in the environment by bringing subsurface heat upward and impacting local sea ice conditions. Likewise, nutrients may be transported upward from depth, which in turn can affect biological productivity.

Broadly speaking, I have grouped the processes that modify water masses by depth, into the "upper ocean" and "interior ocean". The upper ocean is modified by winds as well as seasonally through heating or cooling



▲ Map of mooring locations and bathymetry in Barrow Strait.



▲ The physical processes contributing to the mixing and modification of the waters in Barrow Strait.

and subsequent ice melt or formation. In winter, salt is expelled from ice crystals as they form, making surface waters more saline and denser. During the summer, melting ice releases freshwater, reducing the water density.

By comparison, the stratified ocean interior is largely modified by breaking internal waves. Internal waves are essentially the underwater equivalent of surface waves, but they tend to be much taller, longer, and slower, existing on the order of tens to hundreds of meters in height, kilometers in length, and minutes to hours in duration. Right now, my research is focused on internal waves.

LET'S DIVE DEEPER INTO INTERNAL WAVES

Internal waves form when the interface between water layers is disturbed. When these waves break, turbulent mixing occurs, modifying the interior water mass properties. The two primary mechanisms that generate internal waves are winds and tides.

Let's first talk about wind. When wind blows on the ocean surface, it transfers energy into the upper mixed layer. This energy eventually generates disturbances along the interface between water layers, producing internal waves that propagate downward into the ocean interior. These waves have a frequency near the inertial frequency, also known as the Coriolis frequency, which depends on the latitude and rotation rate of our planet. Hence, they are known as near-inertial internal waves (NIWS).

Now, let's talk about tides, the other dominant mechanism that generates internal waves. As tidal currents slosh over the seafloor, they interact with underwater bathymetric features, such as continental slopes or seamounts. This will generate disturbances along the interface between water layers, producing internal waves at tidal frequencies, known as internal tides (ITS).

NIWS and ITS can travel long distances, redistributing energy throughout the oceans, and when they break, they mix the stratified water layers in the ocean. It is remarkable that things like the winds and tides, which affect our daily lives here in Halifax, also dictate mixing in the ocean interior far away and kilometers below where we experience them.

INTERNAL WAVES IN BARROW STRAIT

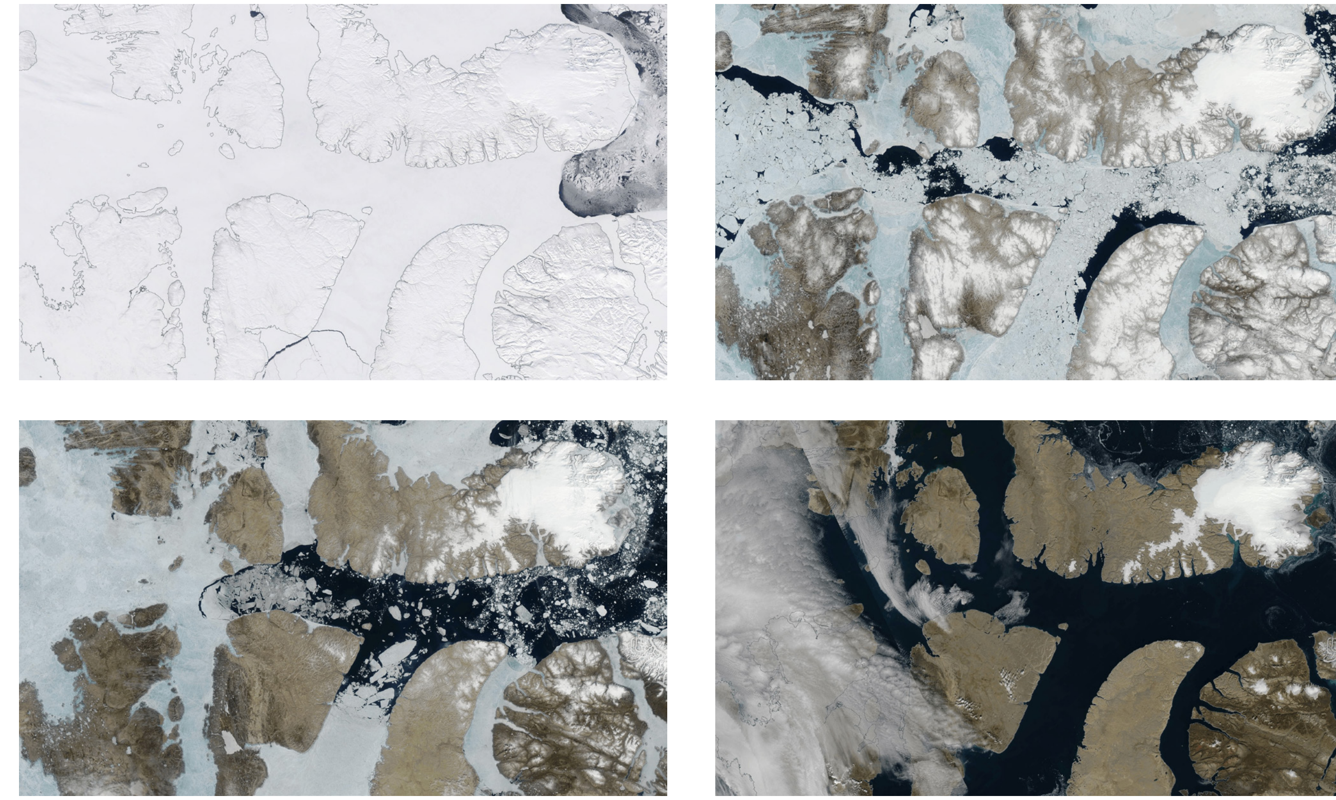
To investigate the properties of internal waves and their spatial and temporal variability, I am using the long-term time series of oceanic, sea ice, and atmospheric properties. In particular, I am examining full water column ocean velocities.

Wind driven internal waves – Much is known about NIWS in mid-latitude open oceans, where seasonal variations in wind typically drive NIW variations, with more NIW energy in winter when storms are strongest. In contrast, less is known about NIWS in polar regions where sea ice isolates the ocean from the atmosphere, and thus winds no longer have direct contact with the ocean, affecting NIW generation. Barrow Strait, which is a channel and has partial sea ice cover for 10 months of the year, provides a unique studylocation to explore NIW dynamics. I aim to answer questions such as: how does sea ice, mixed layer depth or channel boundaries influence NIW generation?

In Barrow Strait, NIW energy is highest in the summer to early fall, which does not align with increased winds, but occurs when the mixed layer is shallow and the ocean is ice free, so wind energy can easily transfer into the ocean. NIW energy is weaker when the mixed layer is deeper and when sea ice covers the ocean. This seasonality in NIWS was observed at all locations across the strait. NIW energy was minorly elevated towards the center of the channel, and is overall smaller compared to the open ocean. In open oceans NIW motion is typically circular, but in Barrow Strait the motion is elliptical along the channel, suggesting that the channel boundaries do influence NIW generation. This research is still ongoing.

Tidally driven internal waves – Properties of ITS are dependent on latitude; when the frequency of the tide is less than the inertial/Coriolis frequency, ITS are not able to propagate freely and instead are topographically trapped near bathymetric features. This occurs poleward of 30°N latitude for the diurnal (1 cycle per day) tide and 74.5°N latitude for the semi-diurnal (2 cycles per day) tide. Furthermore, ITS are typically enhanced in regions of complex and rough bathymetry. Again, Barrow Strait, which has a latitude of 74.5°N and a lot of rough topography, provides an interesting location to explore IT dynamics. I aim to answer questions such as: What is the vertical structure and temporal variability of ITS?

In Barrow Strait, we observed year-round bottom amplification of the diurnal tide (tidal currents are stronger at the bottom), but not for the semi-diurnal tide. We also observed a near surface seasonal damping of the semi-diurnal tide, and less so for the diurnal tide, likely caused by the friction of sea ice cover. The spatial and temporal variations of ITS can help shed light on how mixing patterns emerge. This is still work in progress.



▲ Satellite images illustrating the various ice conditions in Barrow Strait.
Top left: Landfast-ice April 21 2002
Bottom left: Free-drifting ice July 01 2007
Top right: Heavy-ice June 23 2010
Bottom right: Ice-free August 16 2007.

FINAL REMARKS

Recent changes observed in the Arctic due to warming and decreased ice cover will likely impact these ocean mixing processes. For example, sea ice decline will increase the amount of water in contact with the wind, allowing increased wind energy transfer into the ocean and generating more wind driven internal waves, enhancing mixing. This could mix warmer interior waters upward to the colder surface, leading to further ice melt. Changes in water column stratification also impact mixing – a decrease in stratification may permit more mixing, while an increase in stratification would suppress mixing. The extent that water mass modification and mixing processes may change due to warming and sea ice decline is still very uncertain and thus there is a growing need and interest into better understanding these processes in an Arctic framework.

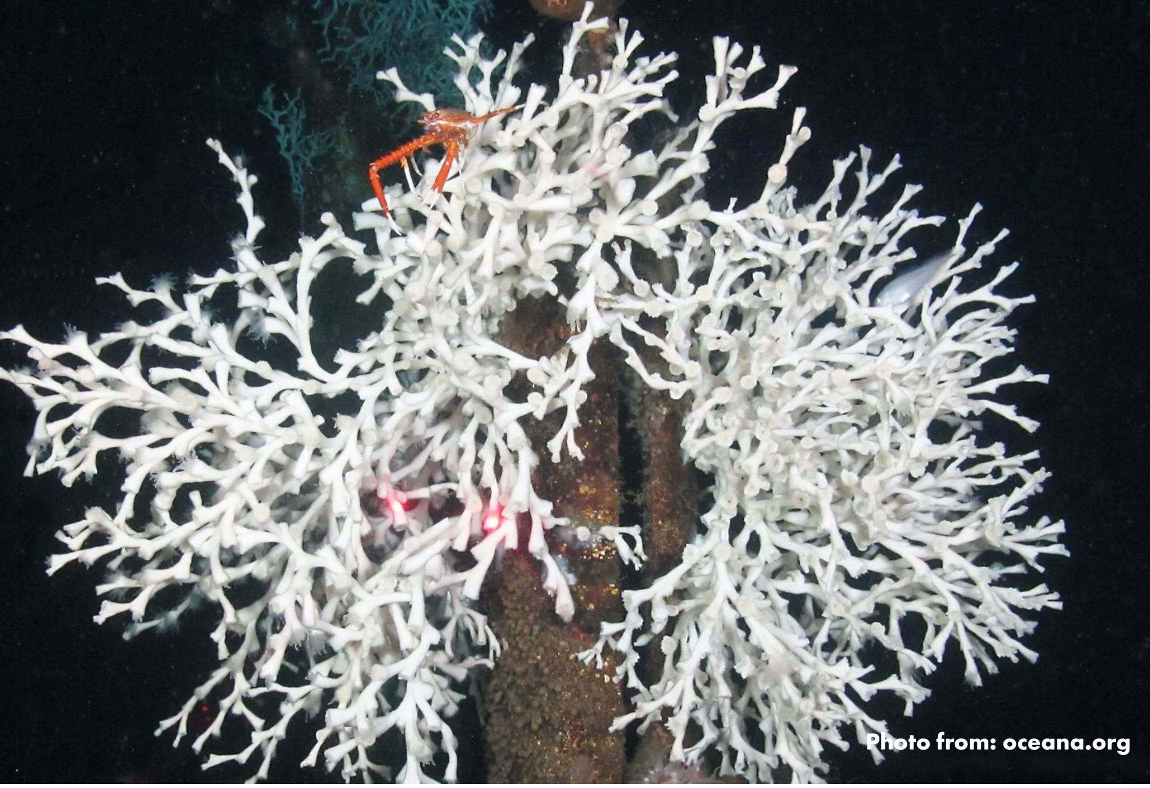
The Arctic is a vital component of the Earth's climate system and has undergone dramatic changes. Regional warming and declines in sea ice cover have been occurring much faster than anticipated – it is now predicted to be seasonally ice free by 2050! This is an enormous shift which influences other parts of the globe through the Arctic outflows. As I continue my research into wind and tidal driven internal waves, we will be improving our understanding of the processes that govern water mass modification and mixing in the CAA, particularly Barrow Strait, and how they may change as the Arctic shifts to a new climate state.

Uncovering Secret Transportation Networks in the Deep Sea

Graeme Guy

HIDDEN BENEATH the vast expanses of the ocean lies a world of wonder and mystery, where ancient corals thrive in deep, dark waters. Deep-sea corals – those that live below about 200 meters – are not so different from their shallow-water cousins, which are famous for building iconic ecosystems like the Great Barrier Reef. The 3-dimensional structure of the coral provides shelter, food and habitat for other animals and they tend to host a high diversity of species. The Great Barrier Reef ecosystem, as an example, is composed of numerous individual reefs, some of which are inter-connected by the movement of animals and flow of nutrients, exchanging resources and genetic information. We refer to this as 'connectivity', and more animal movement between areas equals a higher degree of connectivity, which turns out to be important in maintaining the health and biodiversity of the individual reefs as well as the larger ecosystem. When animals arrive in new areas, they replace aging or damaged individuals and bring in fresh genetic material, which can help populations adapt to potential stressors like warming waters. That's why it's so important to understand which populations are key to connectivity in marine conservation. In comparison to shallow water corals, there has been little research on deep-sea corals, and their ecosystems are far less understood – but we do know they can offer the same ecological benefits, like shelter and food for other species, as their shallow cousins. *Desmophyllum pertusum* is one of the more well studied coral species in the deep sea and is documented to host a higher biodiversity of species than surrounding habitat, making it a foundational species in deep-sea ecosystems. The connectivity between *D. pertusum* populations is also important for their health and function, but there's still a lot we don't know about how this process functions. My research focuses on quantifying the connectivity among *D. pertusum* populations in the North Atlantic Ocean and determining how it changes with different environmental conditions.

A fish patrolling a deep-water coral garden made up of *D.pertusum* (white) and P. arborea (pink) coral colonies



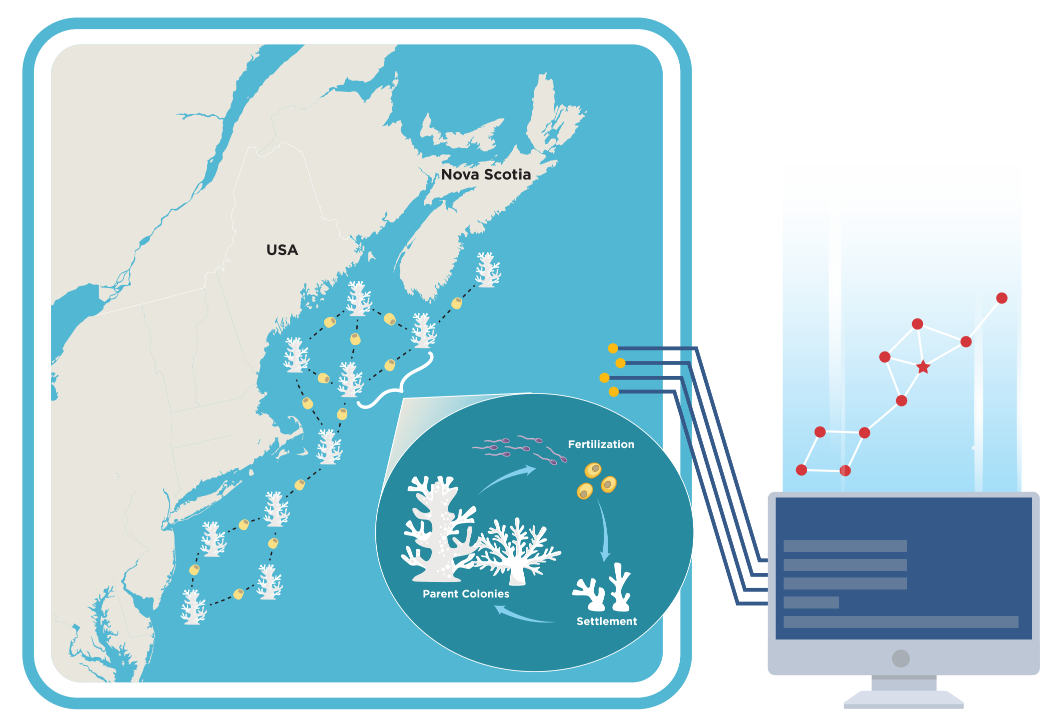
A *D.pertusum* colony with a resident crab and fish

Corals have complex life cycles, and their initial days are spent floating about the ocean instead of securely attached to the sea floor. Fun fact about corals – some species have separate male and female individuals, that produce sperm or eggs, whereas in some species individuals are able to produce both sperm and eggs. *Desmophyllum pertusum* belongs to the former group, with separate male and female adult corals releasing eggs and sperm into the water hoping for fertilization. If fertilization is successful, a young, microscopic coral will begin to form. At this early stage they are called larvae – and don't yet resemble or behave much like their adult form, floating freely through the ocean as a small, gooey, oval-shaped blob. During the larval phase corals grow and develop as they are carried along by the ocean's currents. Eventually, when conditions are right, the larvae will descend to the bottom of the ocean to settle onto a hard surface like rock or rubble, sometimes very far away from their natal location. Once attached, they undergo metamorphosis and begin to grow into their adult form–stationary and anchored in place–where the cycle begins again with reproduction.

There are a few main elements that contribute to how far and in which direction larvae are transported between spawn and settlement, which determines if different populations are connected to one another. Some larvae are passive drifters, and their direction of transport is completely in the hands of the ocean currents, but distance will be related to the duration of the larval phase. Larvae of some coral species are not passive and can swim up or down in the water column - and this matters. Currents tend to be faster near the surface and slower near the bottom and often flow in different directions - so a larva's depth can change how far, and in which direction, it travels. Because ocean currents can also vary across short distances, larvae spawned from different ends of the same reef may experience completely different transportational fates. Larvae grow and develop at different rates because the local environmental conditions, which are highly variable, have some influence on these processes. So, the larval phase doesn't have a fixed duration, but generally, warmer conditions speed up development and shorten the larval phase and cold water has the opposite effect. This means the length of the larval phase can vary with location and depth - even within the same species - which directly influences the distance larvae travel and ultimately where they end up. All this is to say – where and when spawning occurs, and how deep larvae float are the major factors influencing the magnitude of dispersal, all of which can vary in space and time making it challenging to quantify.

In my research, I map and study possible connections between 106 different *D. pertusum* populations in the Northeast Atlantic to understand how the overall ecological system functions as a meta-population of interconnected populations. For this, we turn to Network science, a field used to study everything from air traffic patterns to disease spread, which helps us make sense of these kinds of systems. Consider the air traffic example: some airports, like LAX in Los Angeles, are major travel hubs and handle huge volumes of air traffic with connections to and from dozens of other cities worldwide. Others, like YHZ in Halifax, are smaller with fewer airlines and travel routes to other cities. In the same way, some coral populations act like major hubs with connections to and from numerous other populations (stars in the schematic) which are facilitated through larval dispersal, while others are more isolated. By turning coral dispersal into a network, we can analyze the incoming and outgoing connections for each population and identify which are most important for keeping the whole system connected.

Now, tracking larvae through the ocean and quantifying the connections between populations turns out to be a challenge. We can't track baby corals the same way we track other animals like sea turtles and whales; by attaching GPS tags to their backs when they surface to breath. Coral larvae are less than 1 millimeter long and nearly invisible, and many species of coral look similar as larvae so identifying them takes some serious expertise. So instead, we find adult populations by doing video surveys of the ocean and simulate the larval journey using models. Models are simply representations of the real world; a toy train is a model of a real train, and in science they function as tools to simplify and learn about complex processes we can't measure directly. I used what's called a biophysical model, which uses biological and physical components that we can measure separately and combines them to simulate a complex process like larval dispersal. I combine measured values of larval swim speeds and developmental rates with oceanographic current velocities (modelled from ocean velocity measurements and our understanding of fluid dynamics) coupled with a few mathematical algorithms and a powerful computer to simulate and track how the larvae move through the ocean.



Left: A coral's life cycle beginning with reproduction, fertilization and subsequent transport of the newly formed coral larvae through the ocean in search of a new home, where it will settle and become a member of the resident coral population. Right: Powerful computers and advanced mathematical algorithms are used to simulate larval transport and generate connectivity networks (above) which we use to determine how different coral populations are linked, and infer which populations are the most important for maintaining these connections.

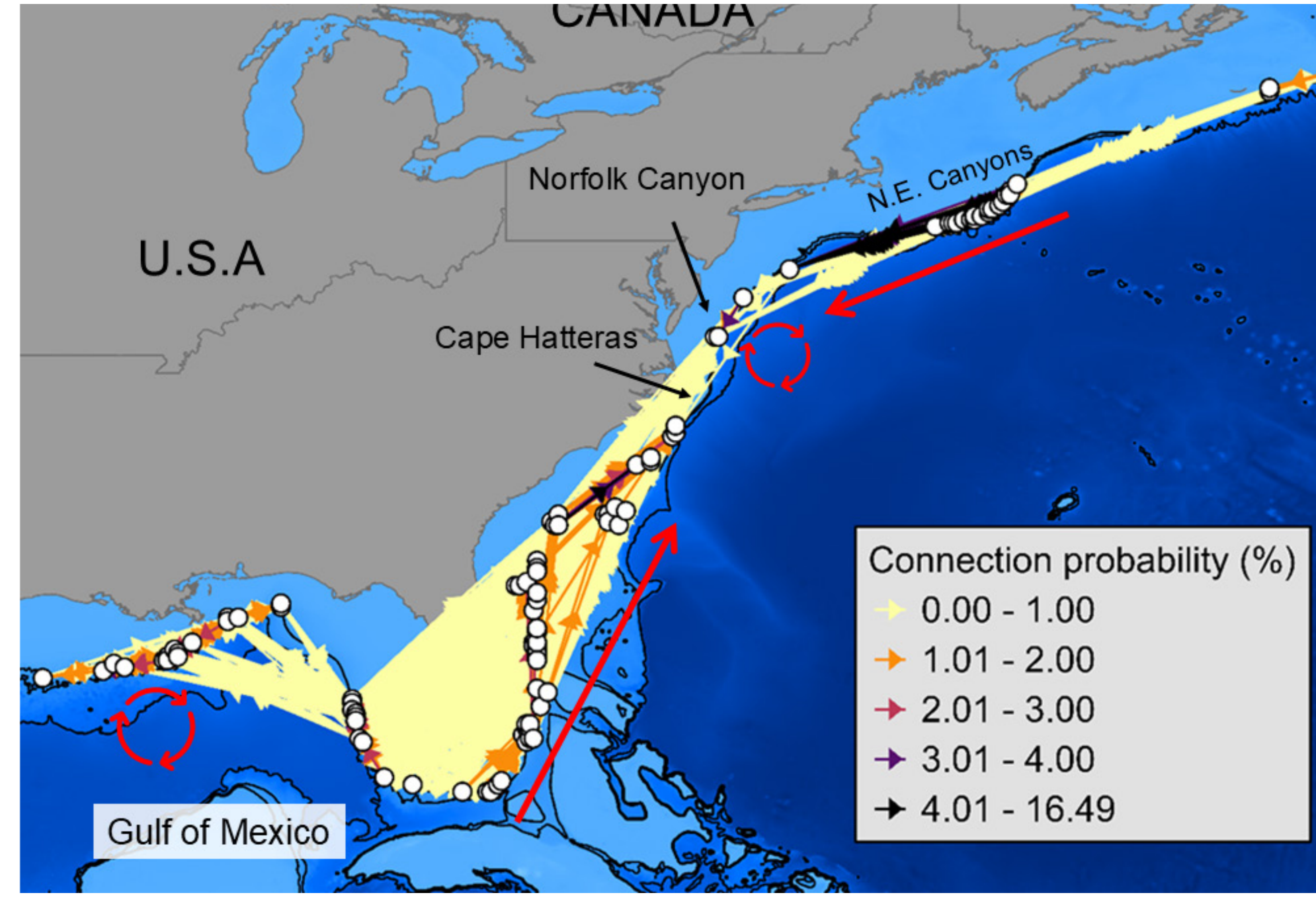
In my research, I used a biophysical modeling to simulate the 3D dispersal of *Desmophyllum pertusum* larvae along the east coast of North America – from adult populations in the Laurentian Channel (between Nova Scotia and Newfoundland) down to the Gulf of Mexico. I wanted to understand which coral populations are linked and whether some populations are more important for maintaining connectivity than others. I also tested how the connections changed when biological factors like development rates, swimming speeds, and spawning season where changes, and what different combinations of these variables looked like.

Three major patterns emerged from my research. First, there's a strong southwestward flow of larvae from the canyons off New England toward Cape Hatteras, North Carolina. Second, I found dense connections between the eastern Gulf of Mexico and the southeastern U.S., especially from eastern Florida to Cape Hatteras. Third, certain areas like Norfolk Canyon and parts of the Gulf of Mexico showed high larval retention — meaning larvae spawned there tend to stay close to home.

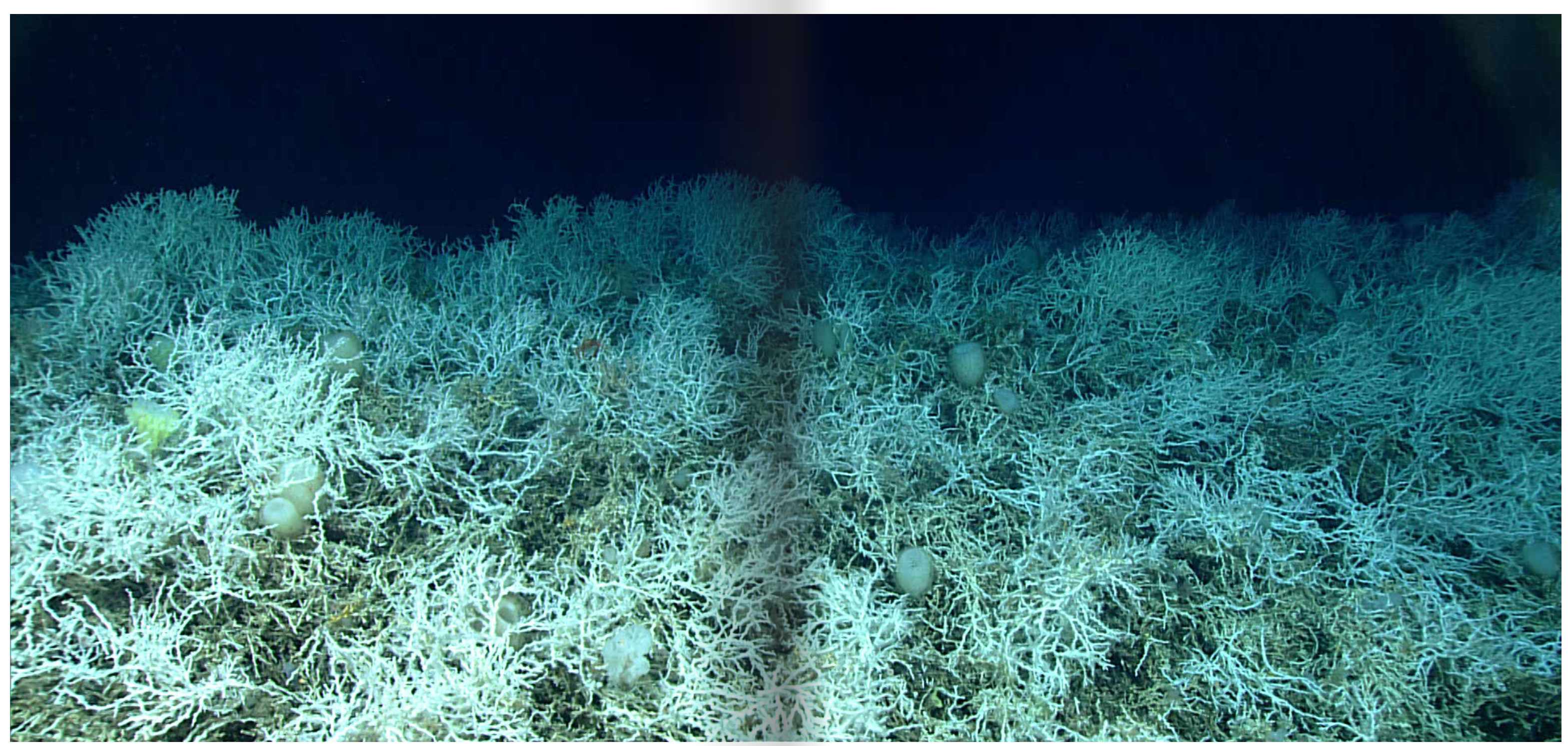
Interestingly, the strength of the connections (strength refers to how many larvae travel between 2 populations – more larvae equal a stronger connection) depended on how quickly the simulated larvae developed and swam. Slower-developing larvae tended to travel farther and formed connections between distant populations, while fast-developers remain closer to their spawning location. Opposite to that, the faster swimming larvae generally travelled further while the slower swimmers stayed closer to home. That's important because development rates depend on water temperature – and the ocean varies by more than 25 °C just between the northern and southern extents of my study area. So, a corals spawning location determines the ocean temperatures they experience, which influences how fast they develop and swim, how far they can travel, and ultimately which other populations they can connect with.

Another important finding was a bottleneck in connectivity between Canadian and U.S. waters. All larval movement between these two regions passes through populations near Cape Hatteras. If corals in that area were lost, it could sever the link between northern and southern populations, isolating them and reducing their resilience. This connectivity bottleneck has been documented in similar connectivity studies for different species, suggesting the local hydrodynamics are the major driver of this feature.

This kind of insight has big implications for how we protect deep-sea corals. Right now, many marine protected areas are chosen based on where corals happen to be – but that's not enough. We also need to protect the places that connect coral populations together. For example, sites with high larval retention, like Norfolk Canyon, may be self-sustaining and should be prioritized for protection. By identifying connectivity hotspots and corridors, we can design smarter, more effective conservation strategies – ones that ensure coral populations remain healthy and resilient in the face of climate change, fishing, and deep-sea mining. These hidden reefs may be out of sight, but thanks to modeling and network science, they don't have to be out of mind.



Map of the study domain in the NE Atlantic Ocean, including major features and white points showing the locations of known *D. pertusum* populations. The large red arrows show the general connectivity patterns, and the connection probabilities between *D. pertusum* populations are shown by the coloured arrows, the direction is shoen by the arrow mid-line. The strongest connections can be seen in the north of the domain (black arrows), from New England Canyons to the southwest, within the Gulf of Mexico, and up the east coast of the United States.



D.pertusum reef mound

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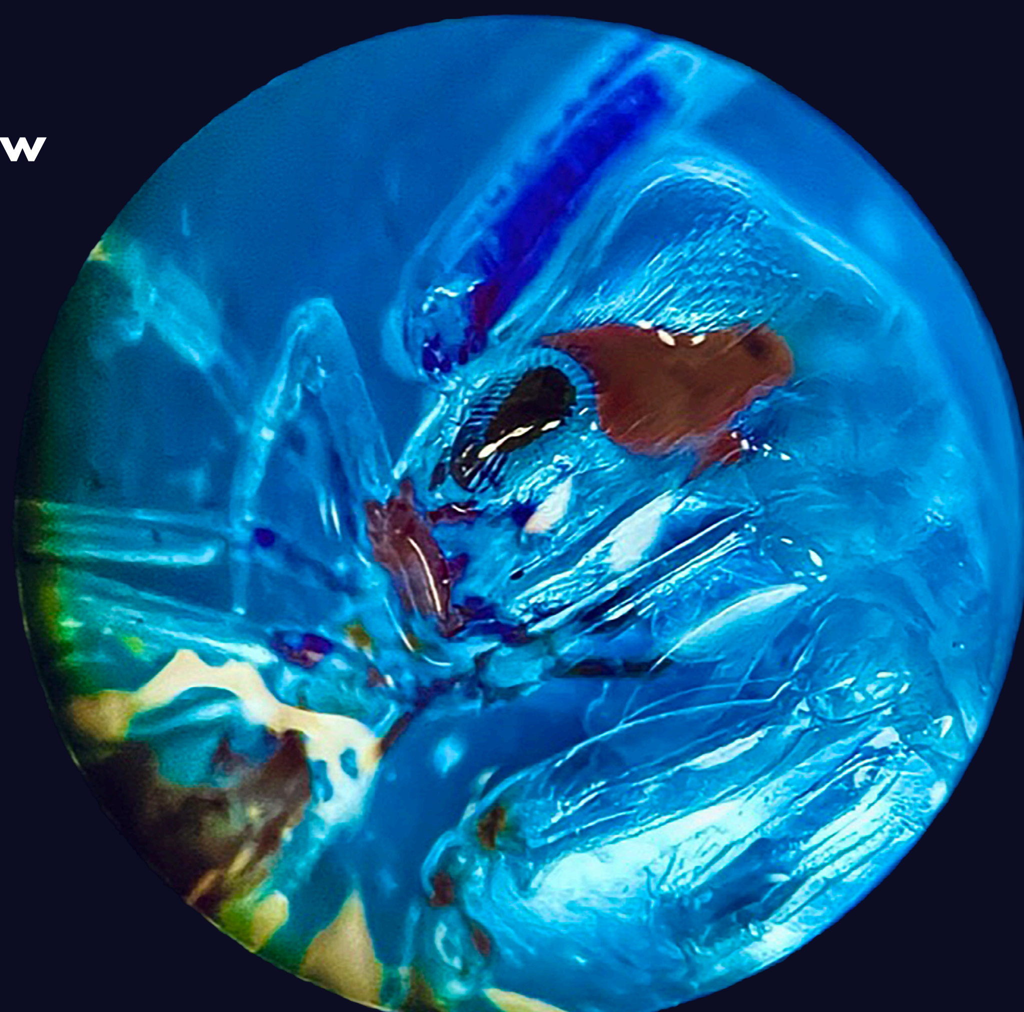
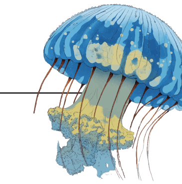
We're Going on an Adventure: A Tale of Ocean Exploration & Zooplankton Recipe Book

Kevan Merrow



Phronima spp. in microscope



THE OPEN OCEAN, vast and blue, is typically described as an ocean desert: endless water with nothing in sight. Or so it seems. But much like an empty refrigerator at 3:00 AM: there's more in there than you might think. Enter zooplankton — animal drifters, as their ancient Greek name suggests — are an extremely diverse group of organisms ranging from big jellyfish to single celled protists. For this story, I'll mainly be focusing on the smaller guys. These little wanderers are the underdogs of the ocean, drifting through the water in large numbers and making up about 40% of marine biomass. Zooplankton, tiny as they are, fuel most of the marine food web, keeping fish, whales, and other sea creatures from going hungry. However, some zooplankton are better fuel than others. Some are nutrient-dense like a fresh kale salad, while others are more like... well, a can of Pringles. And while you could survive on just Pringles, you wouldn't be feeling too great after a while. Just as you might read the nutritional facts on the back of that Pringles can, checking carbs, fats, and proteins, scientists like me study the "nutritional" elements in zooplankton. We look for carbon (C), nitrogen (N), and phosphorus (P). It's a simple recipe, really, but those three ingredients can tell us a lot. C, N, and P are essential elements for living organisms, and zooplankton are no exception. Marine plankton in the surface ocean are expected to have a C:N:P ratio of 106C:16N:1P, which is known as the "Redfield ratio". This ratio has been widely used as a constant in oceanography; however recent studies have shown that some zooplankton differ from this ratio depending on their environment and their species. My research aims to figure out how much of each element is packed into these tiny creatures, and how nutritious they are for the animals relying on them. I am also interested in how the C:N:P in zooplankton might change across environmental conditions such as temperature, and how that recipe might change as our future oceans warm. But first, we had to catch them.

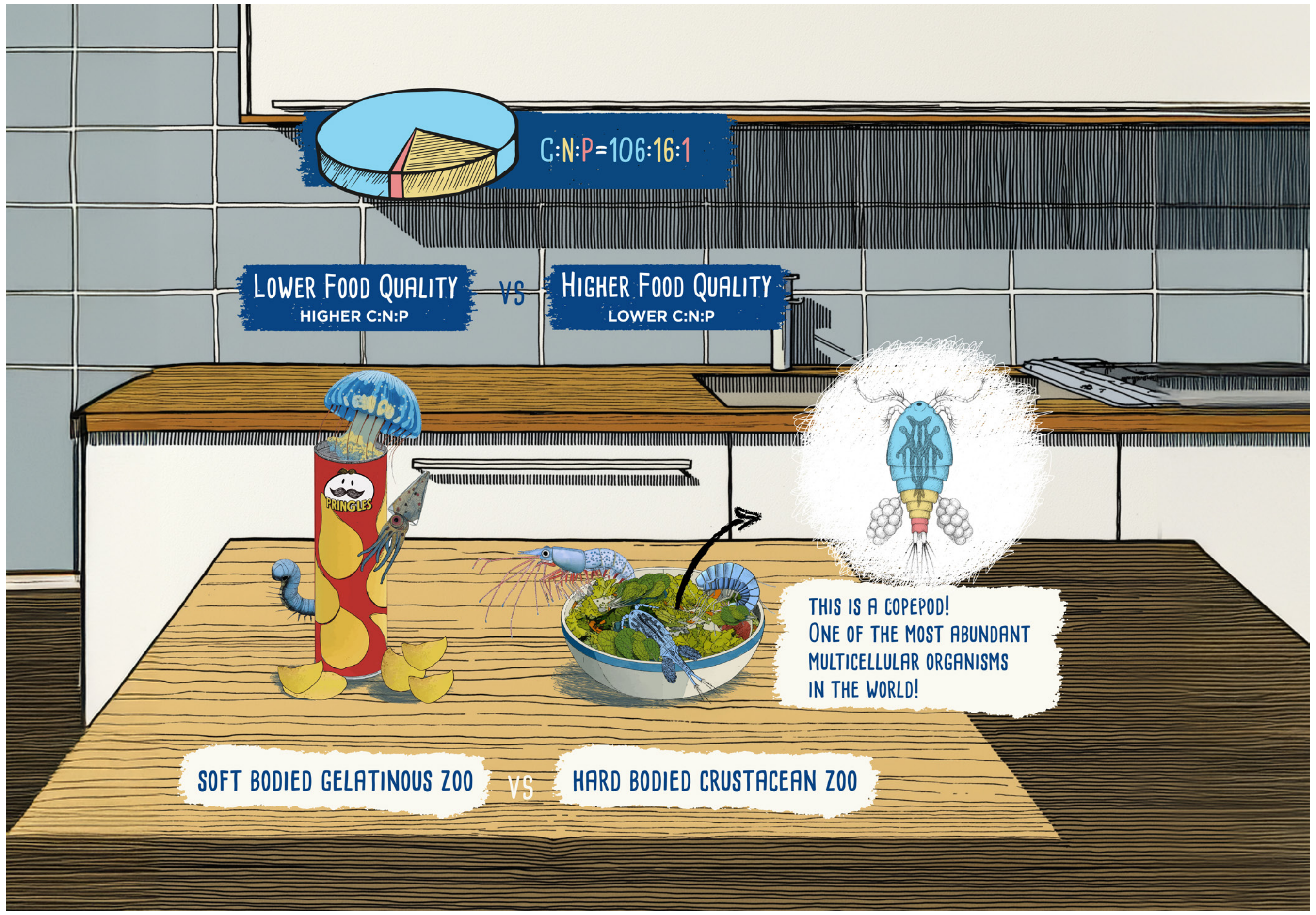
In 2023, I was lucky enough to embark on a month-long research cruise across the North Pacific on the research vessel R/V Thomson. The adventure started in San Diego, cut through the equatorial Pacific, and ended in the tropics in Honolulu, Hawai'i. Not bad for a day's work — or rather, a month's work. This cruise, known as "Gradients 5," was part of a larger project: Simons Collaboration on Ocean Processes and Ecology (SCOPE). Picture this: a ship filled with over thirty scientists from around the globe, all united in the pursuit of one question: how does the ocean work? Our goal was to explore how open ocean communities function and connect across a wide range of environmental conditions (hence the name, Gradients 5). And what better way to do that than by sailing through them?

When I wasn't busy hauling up nets full of plankton or filtering seawater at ungodly hours, I spent my time peering at zooplankton under a microscope. It was mesmerizing — like discovering an alien world. In fact, one of the critters I observed, *Phronima spp.*, even inspired the monster design for the Alien movie franchise.

But the cruise wasn't all work and no play. Amidst the science, there was camaraderie. One of my favorite memories? Playing saxophone on the ship's bow during King Neptune's equator-crossing ceremony — a long held R/V Thompson tradition for both scientists and crew members crossing the equator at sea for the first time. Later, I found myself jamming and playing jazz with the ship's chef below deck. Even in the middle of the ocean, we found time for music and connection. Life, like the ocean, teems with unexpected delights.

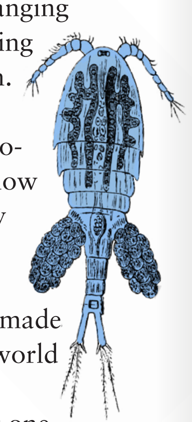
When the cruise ended, I returned to Halifax with a treasure trove of zooplankton samples. Over the next several months, I analyzed the C:N:P ratios across four different size fractions of zooplankton. Why four? Well, zooplankton come in all shapes and sizes. Some are so small you'd need a microscope to see them. Others are large enough to hold in your hand — although I wouldn't recommend it. Certain size groups tend to have similar types or species of zooplankton. For example, crustaceans, like copepods, typically fall into the smaller size fractions and are packed with nutrients and have lower C:N:P values. But larger sized gelatinous zooplankton like jellyfish and salps (remember zooplankton can be big too!) not so much. The difference in C:N:P ratios between size fractions of zooplankton tell us about their different community structures and nutritional values.

So, what's the punchline? Well, the ocean is changing, and with it, the zooplankton community. As the climate warms — especially in tropical regions — the ocean is

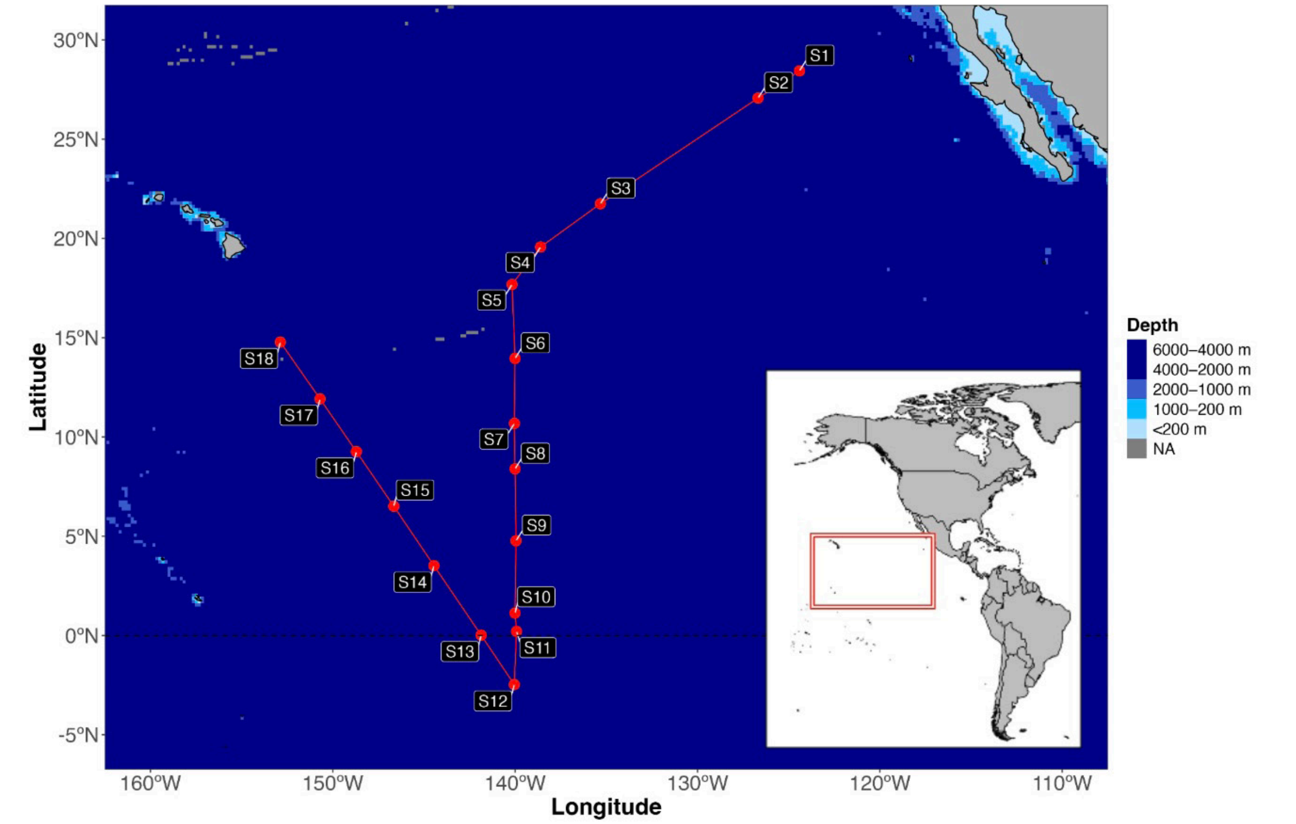


expected to become more stratified, meaning less mixing of surface and deep ocean waters. This could lead to a drop in phytoplankton biomass, the tiny algae that zooplankton eat. When there's less food, we might see more large, gelatinous zooplankton taking over, while smaller, nutritious ones like copepods could decline. This is because larger gelatinous zooplankton typically have higher C:N:P ratios and lower nutrient requirements compared with smaller crustacean zooplankton like copepods. If our future oceans are dominated by jellyfish and their gooey cousins, the marine food web could suffer. Fish and whales rely on smaller crustacean zooplankton for sustenance, and a diet of jelly-like creatures isn't going to cut it in the long run.

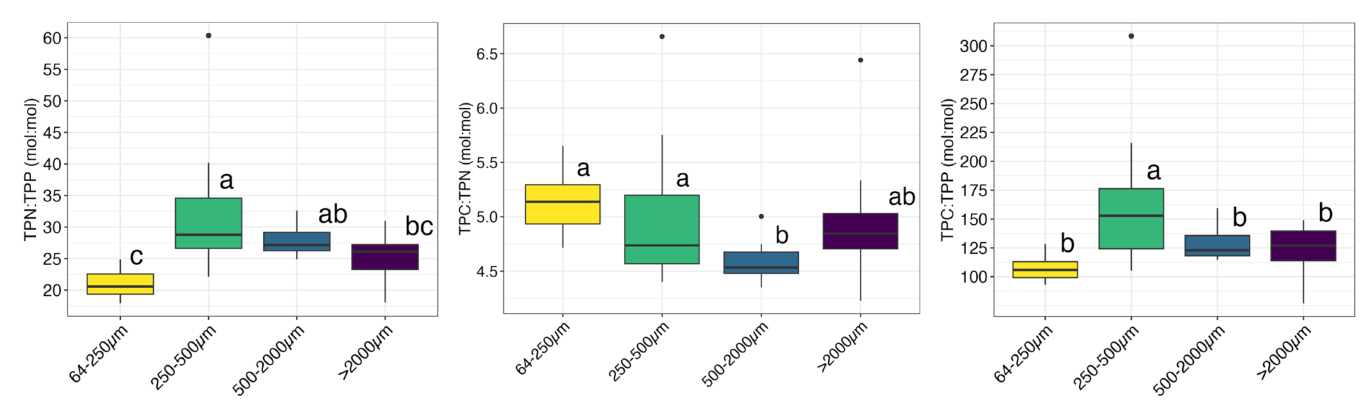
Overall, the median C:N:P across all the zooplankton I studied was 116:25:1, which is strikingly similar to the "Redfield ratio" of 106:16:1. We found significant differences between the size fractions, likely due to the different species in each group. We expected our largest size fraction to be full of gelatinous zooplankton, but, in a surprise twist, we found more crustaceans than anticipated, like krill. We did not find significant differences between the size fractions in relation to temperature and nutrients as we sailed from higher latitudes to equatorial waters. For now, at least, the nutritious zooplankton are still hanging in there — but this could change in our warming oceans, especially in the tropical Pacific region.



We'll need to keep monitoring the C:N:P of zooplankton in the tropical Pacific region to see how potential shifts in the zooplankton community unfold. What's clear is that these tiny drifters play an enormous role in the ocean's complex web of life. And just like you and me, they're made of carbon, nitrogen, and phosphorus. As the world changes, the recipe for ocean life may shift in ways we're only beginning to understand. But one thing's for sure: zooplankton—whether salad or Pringles — are an essential ingredient in the vast and mysterious ocean.



Map of the Gradients IV cruise (TN397) track, sampling stations, and bathymetry. Shapes represent stations within four latitudinal bands: Black squares represent stations in 29º N to 27º N, black diamonds represent 22º N to 10º N, black dots represent 10º N to 5º N, black triangles represent 5º N to 5º S. The thin black line represents the cruise path and the dotted line represents the equator.



Zooplankton C:N:P ratios (mol:mol) in four size fractions. Left: Ratio of nitrogen to phosphorus; Middle: Ratio of carbon to nitrogen; Right: Ratio of carbon to phosphorus. Boxes show data between 25th and 75th percentiles, with the median represented as a line. The whiskers extend as far as the minimum and maximum values not considered as outliers. Letters indicate significant differences (p value <0.05). Purple = >2000 microns, blue = 500 to 2000 microns, green = 250 to 500 microns, and yellow = 64 to 250 microns.

Research on the Rocks: The Importance of Data Preservation and Tenacity in Academia

Emily Sklar

THE GULF OF ST. LAWRENCE (GSL) is busy, to say the least. Vital shipping routes cut through it as the only way from the Atlantic Ocean to the Great Lakes by water. Fisheries haul in hundreds of millions of dollars worth of catch every year. Due to the region's economic importance, there should be great incentive to carefully curate and preserve any collected data therein, such that it can be reused and accessed easily for any future work. Unfortunately, this doesn't seem to be the case.

The knowledge of seafloor substrate composition is crucially important because of the ecological information it can provide us with. The type of substrate present can act as a strong predictor for the fauna inhabiting the area. In soft substrates, such as mud, burrowing animals are abundant. In contrast, hard substrates, like boulders, provide a home for sessile animals to anchor to (as you can see in the article's cover photo). Due to the GSL's ease of access and its importance to the economy, it would be reasonable to assume that the geological properties of the seafloor were well-studied. They were…to an extent.

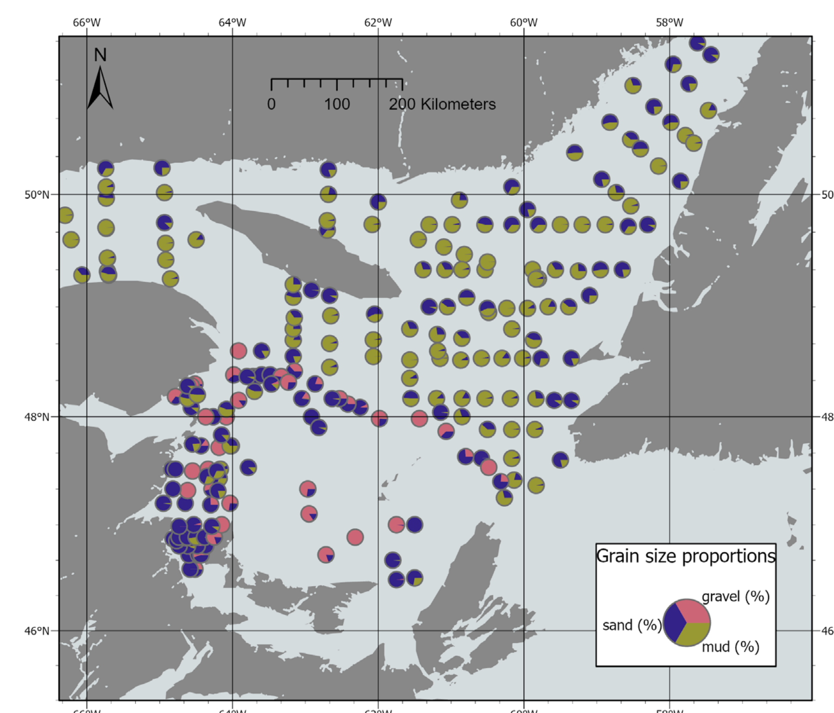
The goal of my thesis is to map the benthic ecology of the seafloor in the GSL. I intend to model habitat suitability for sponges on both broad and fine scales. For the broadscale component, as I needed substrate distribution as a predictor of habitat suitability, I planned to use an existing dataset of approximately 1500 sediment samples to model the distribution of substrate on the seafloor. In the 1960s, these samples were collected throughout the GSL and used to produce a map of substrate distribution. The map shows discrete substrate classes with hand drawn boundaries around the data points by the creators of the map, D.H. Loring and D.J.G. Nota. This was a reasonable approach at the time, but modelling tools have since been developed that can produce continuous representations of substrate with more gradational shifts in class than the original version of the map. Using modern methods, I wanted to create an updated version of Loring & Nota's substrate map. The new version of the map would provide a more realistic, gradational representation of the seafloor and can be used to generate more accurate estimates of habitat suitability for benthic species.

This is where I began to run into problems, because the dataset that was used to produce the original Loring & Nota map could no longer be found. I lost count of how many people I emailed trying to locate this dataset, including Dr. Loring and Dr. Nota (unfortunately they had both passed away), scientists at multiple branches of Fisheries and Oceans Canada (DFO) and universities in Europe who had collaborated with the lead authors. My emails started getting forwarded and bounced around to the point that a DFO employee received my data request six times from six different people (he was very nice about it but unable to help). This data, which surely cost a large amount of money and effort to collect, had simply vanished.

Frustrated and defeated, I was ready to move on. My mission to track down the data had been deemed a failure, until I got an email from a researcher at Natural Resources Canada. She informed me that five old, dusty boxes had been found during the relocation of their offices. These boxes were destined for the trash, but she recognized the name on the boxes, D.H. Loring, from an email she had received from a desperate graduate student (read: me) a few weeks prior. She took a peek inside and found stacks upon stacks of notebooks that mostly contained one thing: substrate composition data from the Gulf of St. Lawrence. I didn't want to believe it out of fear it would turn out to be a dead end. However, cautiously optimistic, I replied and set up a time to go through the boxes myself.

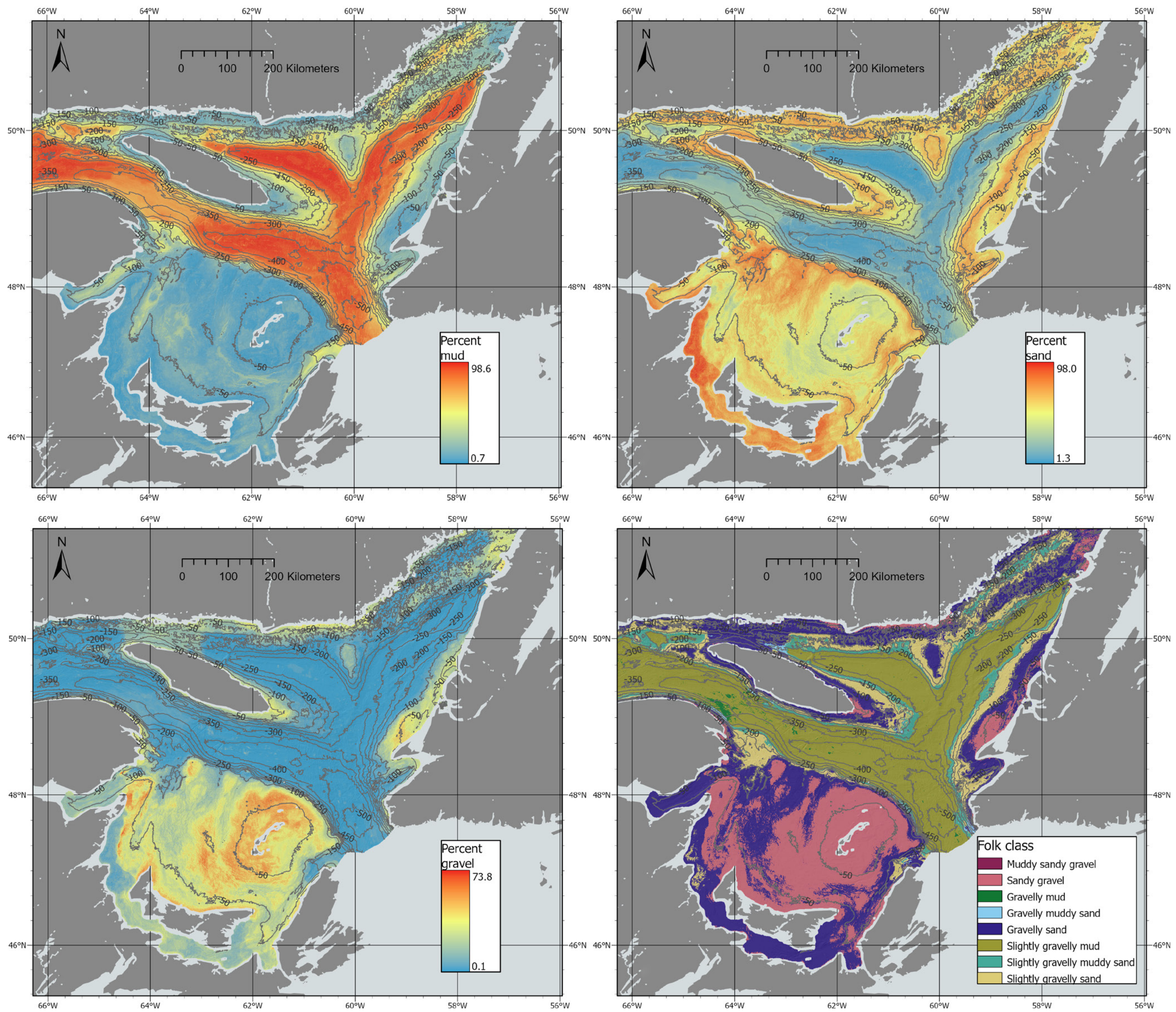
The following week, I spent 9 hours in a warehouse at the Bedford Institute of Oceanography (BIO) flipping through dusty notebooks with mysterious stains and taking photos of the data I so desperately needed. Then, I spent several more hours in my office compiling the dataset into one spreadsheet. In the end, I was able to recover 435 data points from the 1500 samples that had been initially collected. Multiple points were missing coordinates, leading to a lengthy back-and-forth with the head librarian at the BIO Library to track down cruise reports

▲ Notebook pages containing sediment data, recovered from the Bedford Institute of Oceanography.



◄ Distribution of sediment grain size samples from Loring and Nota (1973) that were recovered from the Bedford Institute of Oceanography. Location points are presented as pie charts that indicate the grain size fractions of the given sample.

Scan to read more



▲ Substrate maps created by E. Sklar.: Grain size predictions for mud (Top left), sand (Top right), and gravel (Bottom left) fractions, with Folk classification (Bottom right). Contour lines are at 50 m intervals. Scan QR code for Emily's published work.

to retrieve that information. I was able to attach coordinates to a small handful of points, but the rest were removed from the dataset due to a lack of geographical data. The next step in the data cleanup was to remove any data points in which the total substrate composition didn't sum to 100%. At the end of this ordeal, the final dataset contained 223 points, equivalent to approximately 1 data point per 1000 km^2. This was not ideal for a study area as large as the GSL. However, it was enough to produce an updated version of D.H. Loring and D.J.G. Nota's map of what lies beneath the gulf.

As graduate students, we expect that the largest learning curve in our degrees will involve the scientific knowledge and experience we gain from conducting our research. I expected to write a lot, to spend a fair amount of time doing fieldwork, to improve my coding skills and learn new methods. While these are certainly significant components, they are not the only challenges that we face, as I had to discover first hand while tracking down my data. While the data hunt was more than I'd initially bargained for when I planned to map substrate, it was a useful exercise in being able to persevere and pivot when the time called for it.

From outside of academia, it is reasonable to assume that someone entering graduate school is highly intelligent. One thing that is often overlooked is that people who enter graduate school tend to be just as stubborn as they are smart. I was too stubborn to give up on finding the data, and it is because of how stubborn I was and how many people I contacted in my search that I found it.

I was able to publish my first paper using this dataset, and the results will eventually feed into subsequent chapters of my thesis. I'll be using the substrate maps that I generated to predict suitable habitats for sponges in the GSL. The gulf is undergoing significant warming and deoxygenation, and conservation efforts must be carefully targeted to ensure long term success. I'm excited for a future where I contribute meaningfully to marine conservation initiatives and I cannot wait to see what unexpected hurdles I'll have to jump through next to get there. As frustrating as these hurdles are in the moment, they tend to make good stories once you've overcome them.

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