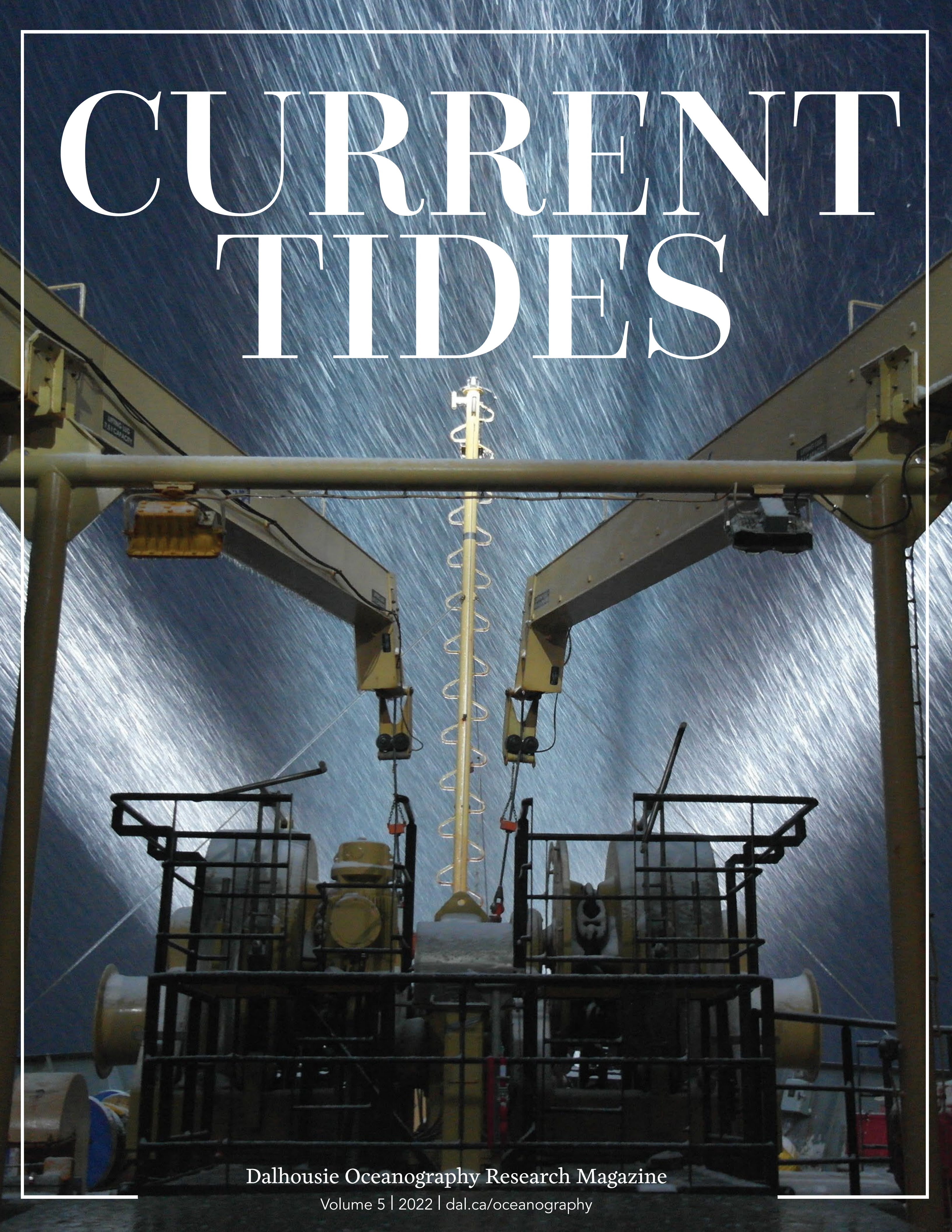
CURRENT TIDES



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Front cover: Photo by Benjamin Richaud. **Left:** Photo by Lina Rotermund. **Right and back cover:** Photos by Lauren O'Dell.

Current Tides

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LETTER FROM THE CHAIR

Katja Fennel
Chair of the Department of Oceanography

One of the absolute favourite parts of my job as Chair of the Department of Oceanography is to sing the praises of our graduate students.

Writing the foreword to this issue of Current Tides, a magazine conceived by, written, and edited by our graduate students, offers a wonderful opportunity to do just that. Especially noteworthy about this issue is that it was put together during the COVID pandemic despite the many challenges presented by lockdowns, university closure, and imposed social isolation. The following pages are full of compelling evidence of the creativity, ethos, determination, competence, and resilience of our graduate students. And they are a fun read.

Conrad teases us with culinary analogs of an undesirable invasive bryozoan that is wreaking havoc on kelp beds in the Maritimes. Ricardo provides a primer on the air-sea exchange of CO_2 in the Labrador Sea. Delphine and Meg tug our heart strings with the story of Punctuation, a now deceased member of the critically endangered North Atlantic right whale species, and then offer common-sense and actionable advice for more effective conservation. Lorenza draws us into a detective story about the fate of anthropogenic CO_2 that starts with the ocean's breathing and involves CFCs as helpful witnesses. Colin compels us to fasten our seat belts when explaining the connections between ocean waves and hurricanes and leaves us eager for improved hurricane forecasts. Jennie delivers a primer on fish surgery and gets us excited about her challenge of finding 20 proverbial needles (in this case Atlantic salmon) in a haystack (an aquaculture pen of 20,000). Nina opens a window to oceans past using chemical fingerprints in ancient corals, mussels, and dead organic matter stored in ocean sediments. And Teala shares stories about her goal to make Remotely Operated Vehicles in the ocean affordable and widely accessible.

Kudos to Editor-in-Chief Arieanna Balbar, the entire editorial and graphics team, and all contributors to the current volume. Your efforts in spreading your excitement, insight, and joys of ocean research make us proud and fill us with hope. ▸

LETTER FROM THE EDITOR IN CHIEF

Arieanna Balbar - Population connectivity & conservation

Arieanna grew up along the Great Lakes, but always yearned for saltier waters. Since moving to Nova Scotia to pursue graduate studies at Dalhousie, she has immersed herself in the Northwest Atlantic Ocean. For her research, Arieanna SCUBA dives amongst lush kelp beds. Field data coupled with physical ocean models allow her to optimize connected networks of marine protected areas for conservation. In her spare time, Arieanna enjoys hopping along the rocky coastline of Nova Scotia and spending time at the local CrossFit gym.

These pages share stories of blood, sweat, and more than likely, tears, and encapsulate the passion of the graduate and undergraduate students in the Department of Oceanography. As scientists, we have a responsibility to communicate our research to a wider audience – a job that is often overshadowed by terabytes of data, pages full of jargon, and the draw to fill our CVs with journal publications. Current Tides is, and has always been, our effort to fill that gap. Enter the COVID-19 global pandemic, that furthered the realization that the field of science is by necessity interactive and social.

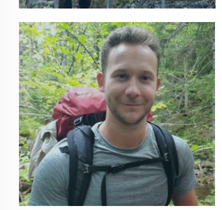
I am so proud of the work that the authors, editorial team, and our graphic designer put into this volume. Editors, thank you for your help updating our website, fundraising, editing, and for being flexible and kind. I am also so grateful to Emily Higgins, our graphic designer, who took my vision for the future of this magazine to the stars. Finally, thank you to the Department of Oceanography and our generous sponsors for your support in producing our cherished magazine.

Without further ado, we hope that you enjoy the stories, photographs, and passions that shine through these pages. Their stories are reflective of the current state of the world around us—tumultuous, unpredictable, and changing—as well as a reminder that collaboration is more important than ever. ▸

EDITORIAL TEAM

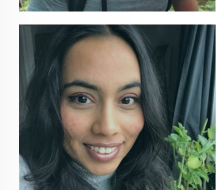
Emmanuelle Cook
Passive acoustic monitoring of Arctic ambient noise

Wendy Muraoka
Prehistoric fish populations

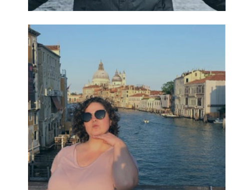


Graeme Guy
Population connectivity of deep-water corals

Brendan Smith
Hydrothermal vent passive acoustic monitoring



Sarah de Mendonça
Deep sea conservation & spatial analysis



Meghan Troup
Shallow water seafloor mapping

Maxime Miron-Morin

February 24, 1991 - April 29, 2020

We dedicate this issue of Current Tides to Maxime Miron-Morin, a DOSA alumnus and dear friend.

Max's unrelenting curiosity, love of a challenge, and thirst for knowledge led him to pursue an MSc in Oceanography while training as helicopter support for the Royal Canadian Navy. His intelligence and dedication to learning are exhibited by his thesis, where he examined the oceanographic contributors to time-variance in the underwater acoustic channel. Underwater acoustic communication may have seemed like another language to his peers, but Max made it look easy. Max was always looking out for others in the graduate student community; he would happily drop anything to help a fellow student figure out a frustrating homework assignment. He even held a term as coffee club co-president (during which he helped run the club into near-irreparable fiscal ruin, primarily due to his dedication to serving high-quality coffee to poor graduate students). Max's humble brilliance remains an inspiration to Oceanography students old and new.

Max loved nature and spending time outdoors. Whether skiing in Quebec, hiking in the pouring rain, canoeing against the wind, or playing soccer with others in the Oceanography department; he was a talented and weatherproof athlete. Max had a great sense of humor and was always ready with a joke to cheer everyone up. He was up for any scheme: whether it was a last-minute camping trip or a night on the town. Max is greatly missed by those lucky enough to know him.

Inset photo by Meg Carr. Background photo by Lauren O'Dell.

NOBODY LIKES THE CRUST

What controls the abundance of an invasive bryozoan?

By Conrad Pratt

Membranipora membranacea encrusting kelp on the Eastern Shore of Nova Scotia. Photo by Robert Scheibling.

A HEALTHY COASTAL SANDWICH

Sandwiched between the land and the open ocean is the subtidal zone, an area deep enough to be constantly submerged but shallow enough to allow light to penetrate to the seafloor (~10 m). On the northeastern coast of North America, this narrow slice of our coastal ocean hosts a thriving ecosystem founded on large marine plants called kelps.

Dense aggregations of kelp, called kelp beds, provide habitat for countless animals and plants and act as a food source for animals both within and outside of the kelp bed ecosystem. However, these leafy greens forming the healthy centre of our coastal sandwich are under threat. The cause? The scourge of children (and many adults) everywhere: the crust.

THE CRUST

The crust I'm referring to here isn't the nutritious margin of a loaf of bread, but rather an invasive organism not native to our shores that made its unwelcome arrival approximately three decades ago in the ballast water of ships arriving from Europe. *Membranipora membranacea*, known colloquially by the contrastingly morbid and dainty names "coffin box" and "lacy crust" (we'll go with the nicer-sounding one), is a type of colonial invertebrate called a bryozoan: colonial meaning that it is composed of many small units functioning together[1], and invertebrate meaning it lacks a backbone. The bryozoan forms a thin, crusty membrane on the surface of kelps and uses this vantage point to capture tiny particles from the water column to eat. This may seem fairly innocuous, but don't be fooled – this organism is more malevolent than you might expect. In the autumn of every year, the lacy crust reaches high levels of cover on kelp blades, weakening their tissue and leaving them vulnerable to be ripped apart and killed by high-energy waves during fall storms. The greater the surface area of kelp covered by the lacy crust, the more kelp we lose. The lacy crust has had a devastating impact on kelp beds in New England and Eastern Canada, with some sites recording greater than 90% losses of kelp since its introduction.

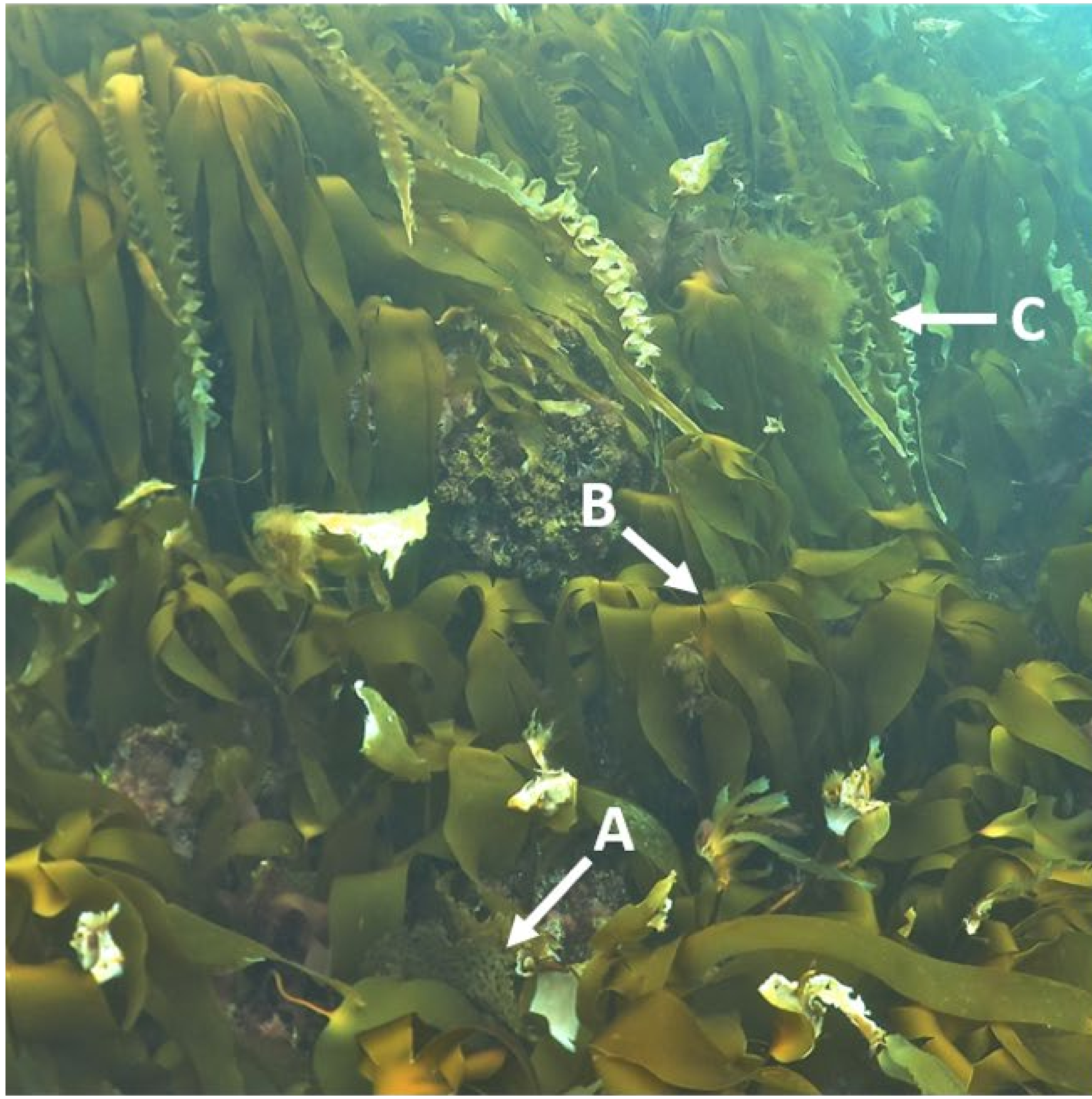
CAN WE CUT IT OFF?

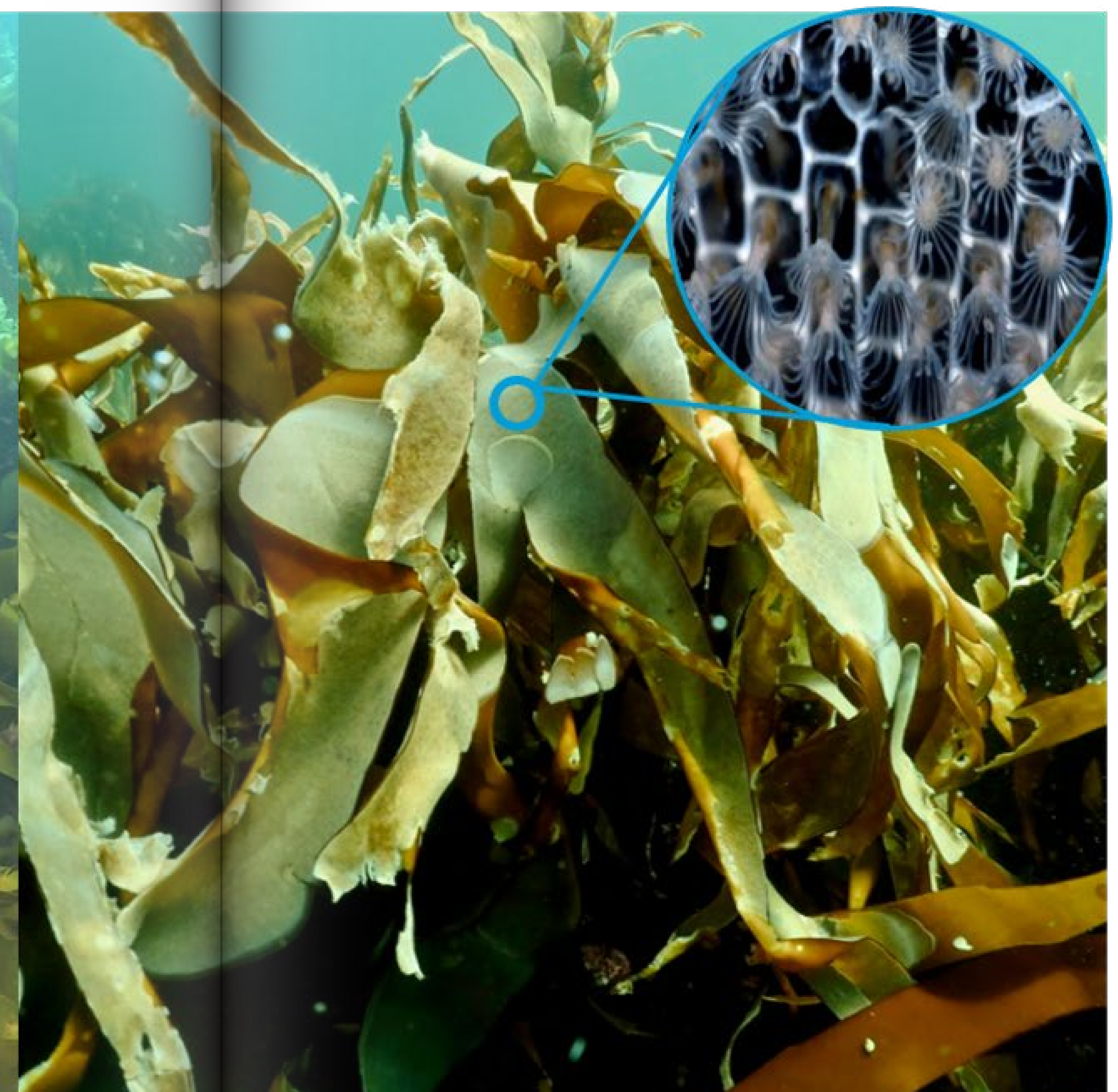
So, we've established that the lacy crust bryozoan is a much more sinister version of lace than your grandmother's doily. But what can we do to save the kelp beds we do have left from destruction at the hands of this crusty invader? Unfortunately, unlike the crust on our PB & J, it's not as easy as simply cutting it off – the bryozoan is literally attached to the species we want to protect. Even if we did painstakingly scrape it off of kelps at a single location, the effort would be futile since lacy crust larvae can travel tens of kilometers via ocean currents and could recolonize the site from elsewhere. Biologically controlling the outbreak by introducing a natural predator[2] of the lacy crust is too risky, as the predator could itself become an invasive species. Our best bet is to take a more defensive approach and protect Eastern North American kelp beds from other stressors (e.g., trawl fishing) by establishing marine protected areas[3] in places where the lacy crust is unlikely to damage kelp. To accomplish this, we need to predict the current and future locations of these areas, and to make those predictions we need to know what controls the % cover of the lacy crust on kelps. That's where my research comes in.

[1] See Danielle Denley's article in Volume 2 of Current Tides for an in-depth discussion of coloniality in *M. membranacea*.

[2] Nudibranchs ("sea slugs") are one of the organisms that control lacy crust populations in regions where it is native. These are also some of the more flamboyant characters in the sea, so I definitely recommend perusing some photos of them online!

[3] Think national parks, but in the ocean. For more information about marine protected areas, click here.





Left: A lacy crust-free kelp bed in the Eastern Shore Islands in July, composed of A) shotgun kelp (small and holey; *Agarum clathratum*), B) oarweed (large and split into multiple straps; *Laminaria digitata*), and C) sugar kelp (long with frilled edges; *Saccharina latissima*). **Right:** Oarweed covered with lacy crust in the Eastern Shore Islands in October (inset shows close-up of a colony with feeding apparatus). Credits: Robert Scheibling (kelp photos) and Lovell and Libby Langstroth © California Academy of Sciences (lacy crust close-up).

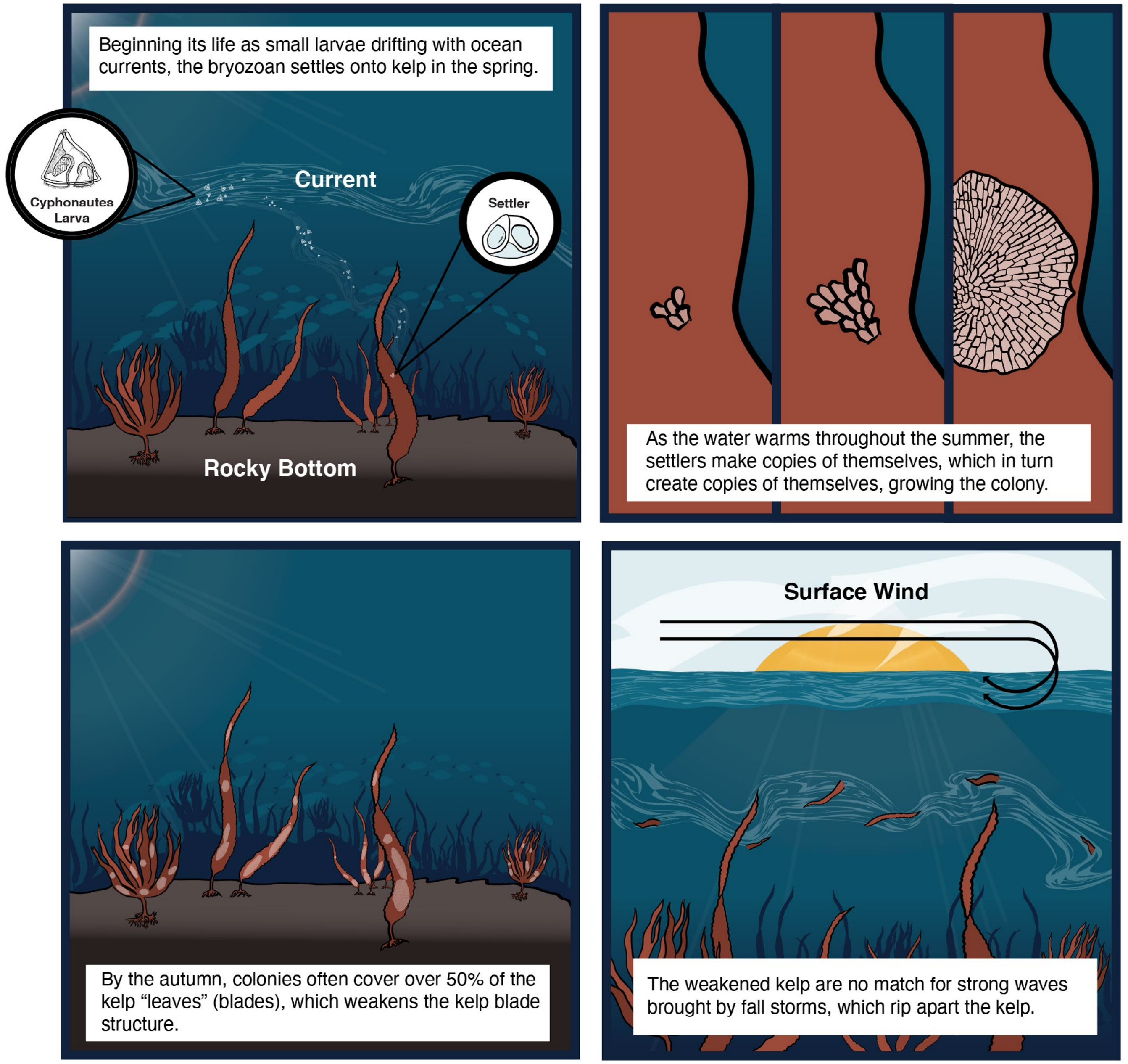
FINDING A RECIPE

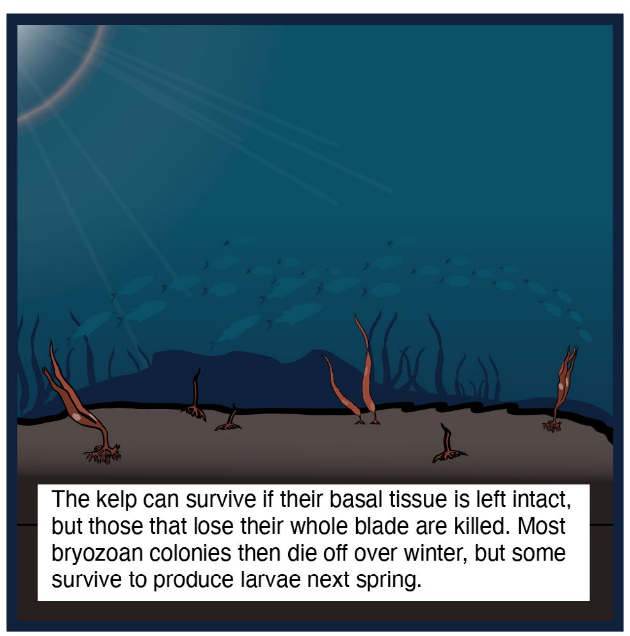
Much like a sandwich[4], scientific research is built in layers, with new knowledge being founded on the findings of previous studies. So, to determine what factors affect the % cover of lacy crust on kelp, I started poring over the existing scientific literature. Sea water temperature was the number-one contender – lacy crust prefers warm water and is more abundant in warmer years. Studies also suggest that the bryozoan is affected by the species of kelp it lives on, the degree of wave exposure, and the density of a kelp bed. However, we still aren't sure if these relationships are the same over larger areas and longer periods of time, and some of these variables haven't been investigated in much detail. So, armed with this "recipe" of background information, it was time to fill these knowledge gaps by adding my layer to our proverbial sandwich of knowledge.

ADDING A LAYER

As with any recipe, my first task was to gather the "ingredients": data on the % cover of lacy crust and its potential predictors in Eastern North America. This mostly involved digging up pre-existing data from published scientific articles, but I was also fortunate enough to spend multiple field seasons scuba diving on the beautiful Eastern Shore Islands of Nova Scotia, collecting data to add to the historical observations I had gathered. I then began the long and arduous process of finding the optimal mathematical model (equation) to predict the % cover of lacy crust. This involved building generalized linear mixed models (basically a more complicated version of a "y = m(x) + b" equation from middle school algebra class) composed of different predictor variables, and systematically comparing their performance to determine the best combination of variables to include in the model. The predictors I tested were water depth, kelp species, and multiple parameterizations of sea surface temperature[5], wave exposure, and kelp density. To sum up many months' worth of work in one sentence, I found that you only really need to know the water temperature,

[4] Yes, I'm repurposing this analogy – it's surprisingly useful!
[5] This is the easiest form of water temperature data to obtain for large-scale modelling, as it can be detected via satellite and there are a wide variety of datasets available.





"Much like a sandwich, scientific research is built in layers, with new knowledge being founded on the findings of previous studies."

- Conrad Pratt, Dalhousie University

Photos from Metaxas Lab fieldwork in the Eastern Shore Islands of Nova Scotia by Emily Higgins (left) and Arieanna Balbar (right).

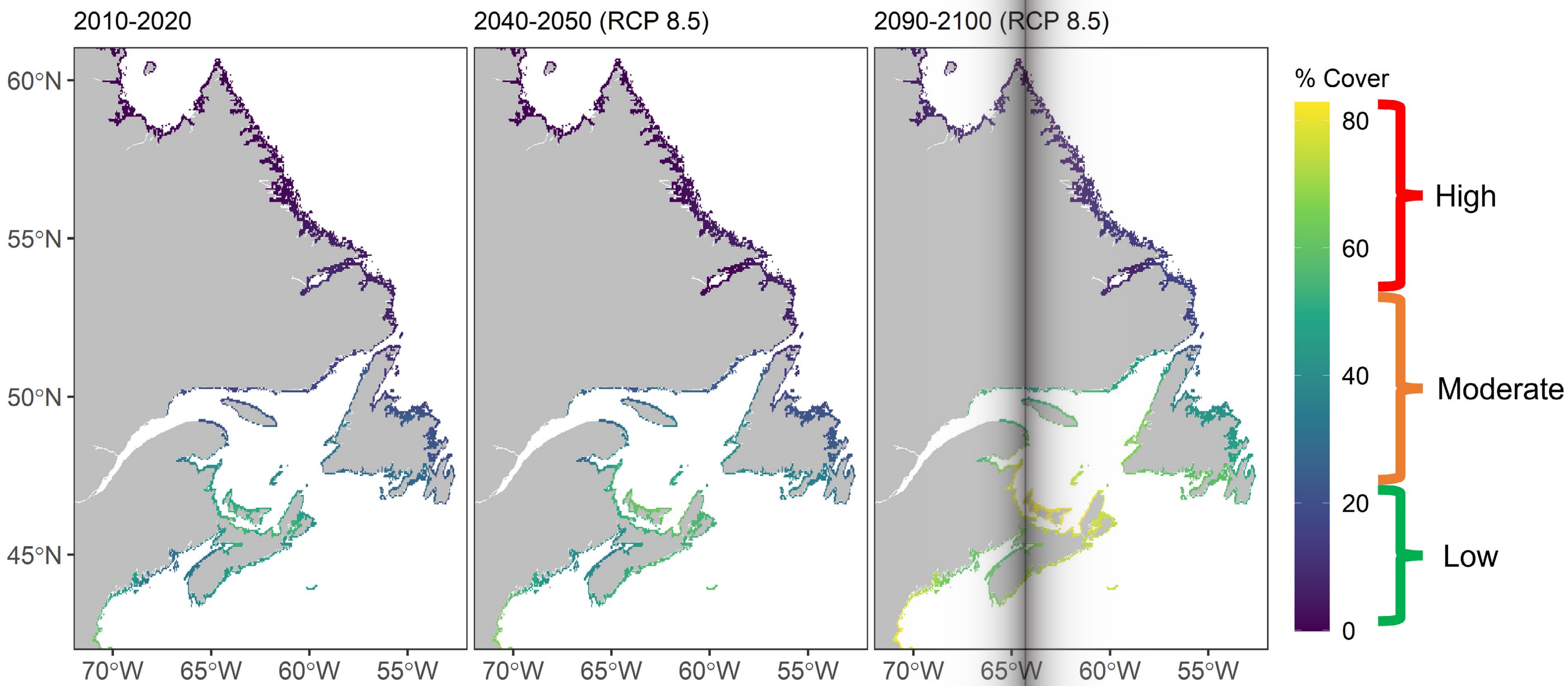
water depth, and the kelp species in order to accurately predict the abundance of the bryozoan. Temperature was the most important variable, specifically, over the six months before you measure lacy crust cover. This finding is consistent with prior research, as we know that temperature directly affects multiple processes in the bryozoan's life cycle including colony growth, the amount of newly settled colonies, and when in the year settlement begins.

Armed with my hard-won mathematical model, I set about using it to predict the maximum possible % cover of lacy crust under different temperature conditions and across space and time. I produced maps of lacy crust abundance under present-day (2010-2020) average temperature conditions, and in average conditions as they are projected to be between 2040-2050 and 2090-2100[6], by feeding maps of temperature for these different scenarios to my mathematical model. My maps extend over the current geographical range of the lacy crust but also northward, up to the northern tip of Labrador in the Arctic, where the bryozoan hasn't yet been recorded, so that we can see if it may invade the lush kelp beds of that region in the future.

SAMPLING THE SPREAD

My maps of lacy crust cover under present-day conditions predicted a general pattern of decreasing cover with increasing latitude: high cover levels in the south (~50%), moderate cover levels at mid-latitudes (~30%), and very low in the Arctic (<5%). This fits with existing knowledge of how lacy crust has behaved in our region, wreaking havoc on kelp beds in the south with diminishing impact in cooler areas further north. However, under future climate warming, the

[6] There are many different mathematical models for future climate, and multiple scenarios for greenhouse gas emissions that determine the output of these models. For my project, I employed climate projections from Bio-ORACLE, a widely-used marine data repository, under RCP 8.5, a high-greenhouse-gas-emissions climate change scenario.



Predicted cover of lacy crust on oarweed kelp under present-day (2010-2020 average) temperature conditions, temperature conditions in 2040-2050, and temperature conditions in 2090-2100. Approximate qualitative categorizations of the risk to kelp (low, moderate, and high) associated with different ranges of lacy crust cover are displayed with the colour bar.

picture changes. By mid-century, we see increases in cover of up to 15%, potentially crossing a literal breaking point for kelp beds in regions like northern Nova Scotia, where lacy crust cover is currently only of moderate risk to kelps but could increase to high risk. By the end of the century, lacy crust is predicted to reach extremely high levels of cover (up to 80%) in New England and the Maritimes, as well as high levels in southwestern Newfoundland and the northern Gulf of St Lawrence (up to 65%). These are dangerous levels of cover for kelps, as past research found that 50% peak cover and above causes substantial losses of kelp beds. The bryozoan is predicted to achieve modest levels of cover (~20%) in eastern Labrador under end-of-century conditions.

KEEPING SALAD ON THE MENU

Looking at maps is fun, but let's return to our original question: which areas should we protect to give kelp beds the best chance of survival? The bad news is that most of New England and the Maritimes appear vulnerable to high lacy crust cover in the future, and it turns out we can't count on mid-latitude regions like southwestern Newfoundland and the northern Gulf of St Lawrence to remain low-impact areas either. However, there are a few areas of relatively low lacy crust cover even as water temperatures warm in the future: for example, the eastern coasts of Newfoundland and Labrador are projected to host only moderate lacy crust cover by the end of the century. By protecting kelp beds in these areas from other threats, we may be able to maximize our chances of maintaining kelp populations in our region into the future. Or, so says the model!

MAINTAINING OUR APPETITE

Although the model I built is a useful tool for making educated guesses about the distribution of lacy crust, it is still a simplification of reality, and reality can prove to be much more complex. For example, kelps on the Eastern Shore Islands appear to be more resistant to damage by lacy crust than kelps elsewhere in Nova Scotia. This may be due to the area's high wave-exposure, which causes the kelp to grow tougher and more resistant to breakage. Therefore, this area may be suitable for kelp protection despite relatively high coverage of lacy crust. Additionally, there is inherent uncertainty in the future sea water temperature projections upon which my maps are based; they are essentially educated guesses about humanity's future environmental policy and the resulting fossil fuel emissions. All in all, there are always more layers to be added to our knowledge sandwich. And if that means more opportunities to dive amongst lush kelp beds like those of the Eastern Shore, I don't imagine there will be any problem maintaining our appetite. ▶

This research was funded by the National Science and Engineering Research Council (NSERC), a Nova Scotia Graduate Scholarship, the Ocean Frontier Institute, and the NSERC Canadian Healthy Oceans Network and its Partners: Department of Fisheries and Oceans Canada and INREST (representing the Port of Sept-Îles and City of Sept-Îles.

Conrad Pratt, Biological Oceanography

Despite growing up surrounded by the ocean in Halifax, Nova Scotia, Conrad didn't spend a lot of time in or on the water during his childhood. However, he was always interested in nature and environmental issues. This eventually led him to (both literally and figuratively) dive into marine science to pursue an M.Sc. in biological oceanography at Dalhousie University. Since completing his master's in September 2021, Conrad has kept working in kelp ecology, and hopes to continue with marine conservation work in the future. Out of the water, Conrad has various passions including traveling, music, and learning new languages.

Conrad conducting fieldwork in the Eastern Shore Islands. Photo by Robert Scheibling.

THE LABRADOR SEA

A data desert for CO_2 fluxes

By Ricardo Arruda Monteiro da Silva

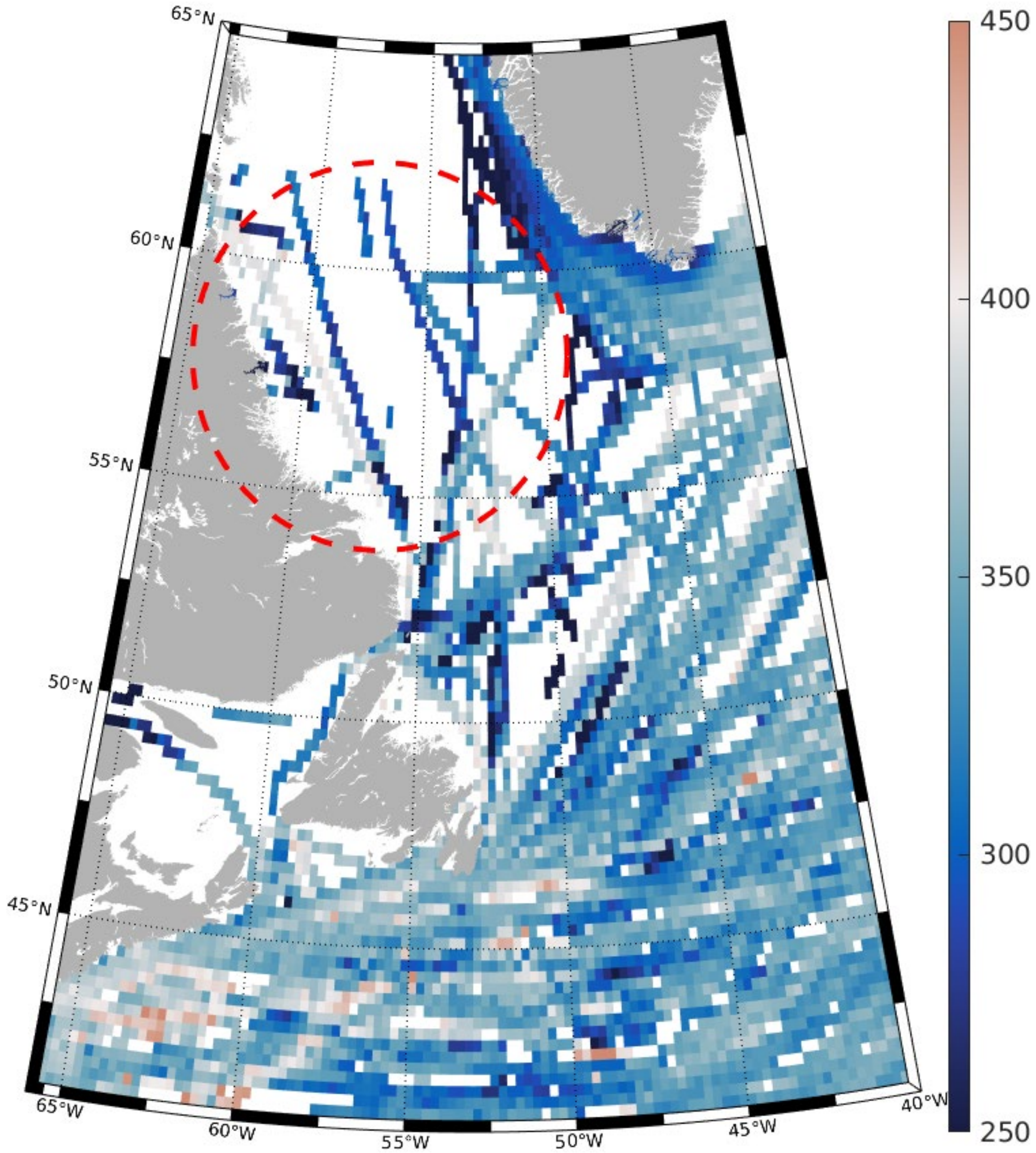
Understanding the global carbon cycle is extremely important for dealing with future climate changes. The absorption of atmospheric CO_2 by the oceans is a key factor in reducing the concentration of this greenhouse gas in the atmosphere. My PhD focuses on measuring these ocean-atmosphere exchanges and investigating their strength and variability. In order to do this, key variables that must be measured are the partial pressures of CO_2 in the water and in the air (pCO_2). Simply, if the surface ocean pCO_2 is lower than that of the overlying atmosphere, CO_2 will be transported from the air into the water (ocean absorbing CO_2). The opposite will happen if the surface ocean pCO_2 is higher than the atmospheric pCO_2 (ocean releasing CO_2).

The Labrador Sea, where my study takes place, is an important region that absorbs more CO_2 than the North Atlantic Ocean average. This flux of gases from the atmosphere to the surface of the Labrador Sea is extremely variable both in time and space, and we do not currently have enough measurements (or observations) of pCO_2 to fully understand this variability. The map of pCO_2 observations for the Northwestern Atlantic Ocean shows the lack of observations of the Central Labrador Sea and Labrador Shelf, particularly when compared to the rest of the region.

OBSERVATIONS

When we go out to sea, either on a research vessel or by sending out a robot equipped with sensors, we measure (or observe)

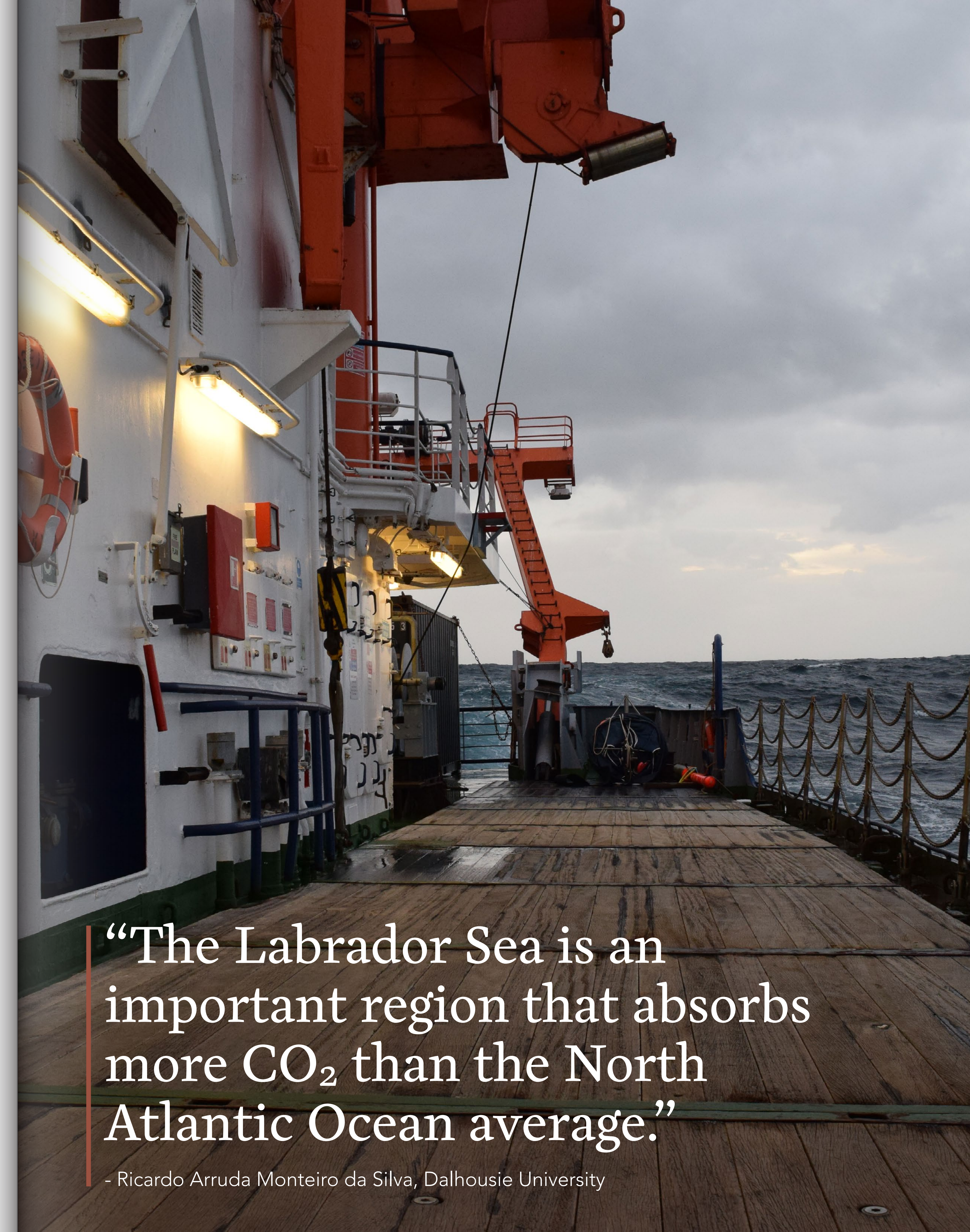
> "A complex interplay of opposing forces drives the changes in pCO_2 and CO_2 fluxes between the atmosphere and the ocean."



Left: Map of observations of pCO_2 available for the Northwestern Atlantic Ocean from 2000 to 2020. Blue colors indicate ocean pCO_2 below atmospheric (absorbing), and red colors indicate pCO_2 higher than atmospheric (releasing). The red circle shows the Labrador Sea. **Right:** Photo taken onboard the research vessel Poseidon, during an expedition in 2018 in the North Atlantic Ocean. Photo by Ricardo Arruda Monteiro da Silva.

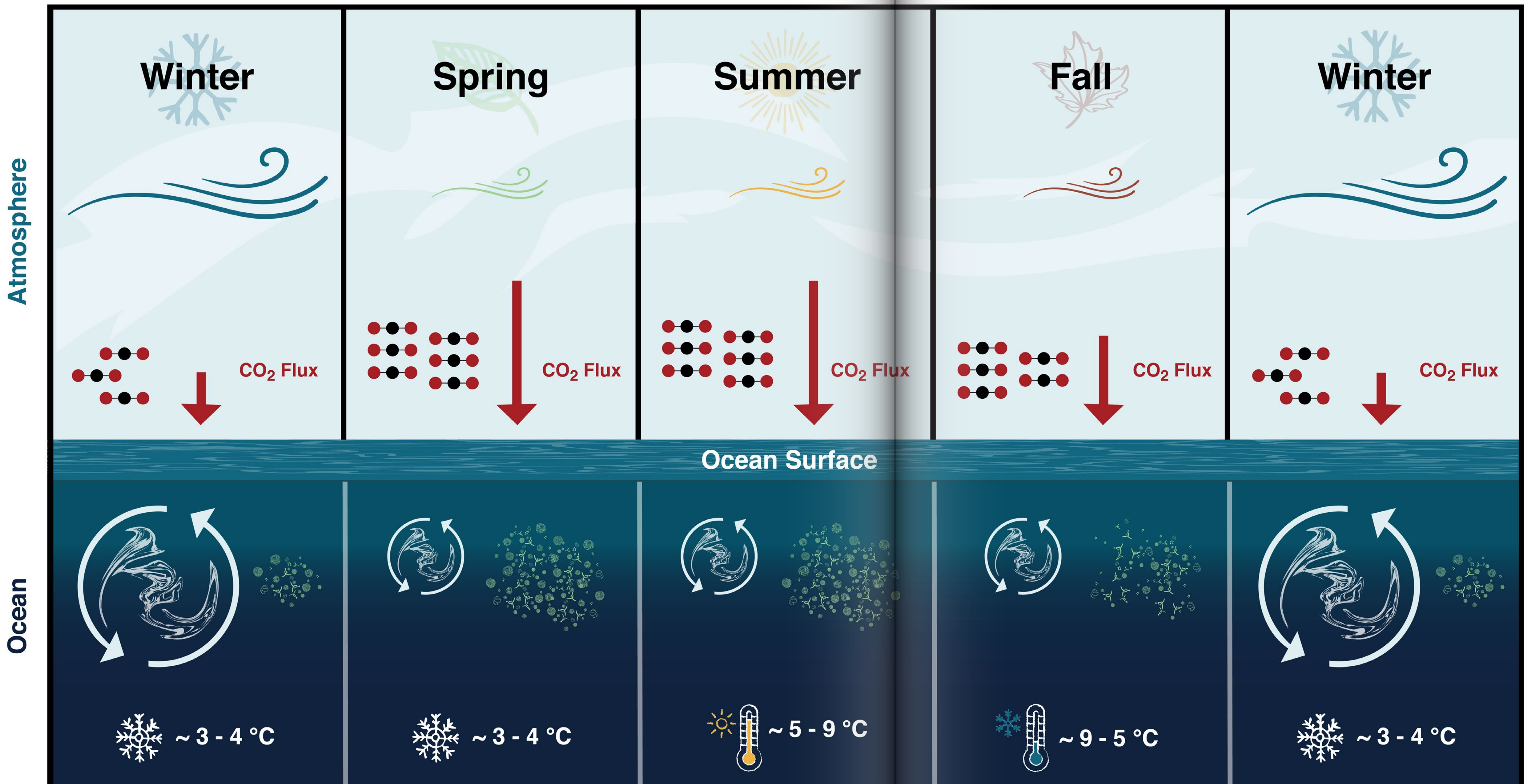
many different things (including pCO_2). These observations come mainly from "underway measurements", where vessels equipped with sensors constantly gather measurements as they sail across the oceans. As a part of my PhD, I participated in 3 cross-Atlantic cruises measuring pCO_2 and did quality control for many more research expeditions. Another important part of my PhD has been comparing and validating different types of pCO_2 sensors, including a new and more compact sensor that can potentially increase our observational capacity in the future.

Another source of observations is "moorings", sensors fixed in one location for a prolonged period of time. For the Central Labrador Sea, there are only a few underway measurements and only four moorings, deployed between 2000 and 2020. Each mooring collected data for one year before it was retrieved. These few but extremely valuable observations of pCO_2 will be used to describe the behavior of the fluxes of CO_2 throughout the seasons in the central part of the Labrador Sea.



"The Labrador Sea is an important region that absorbs more CO_2 than the North Atlantic Ocean average."

- Ricardo Arruda Monteiro da Silva, Dalhousie University



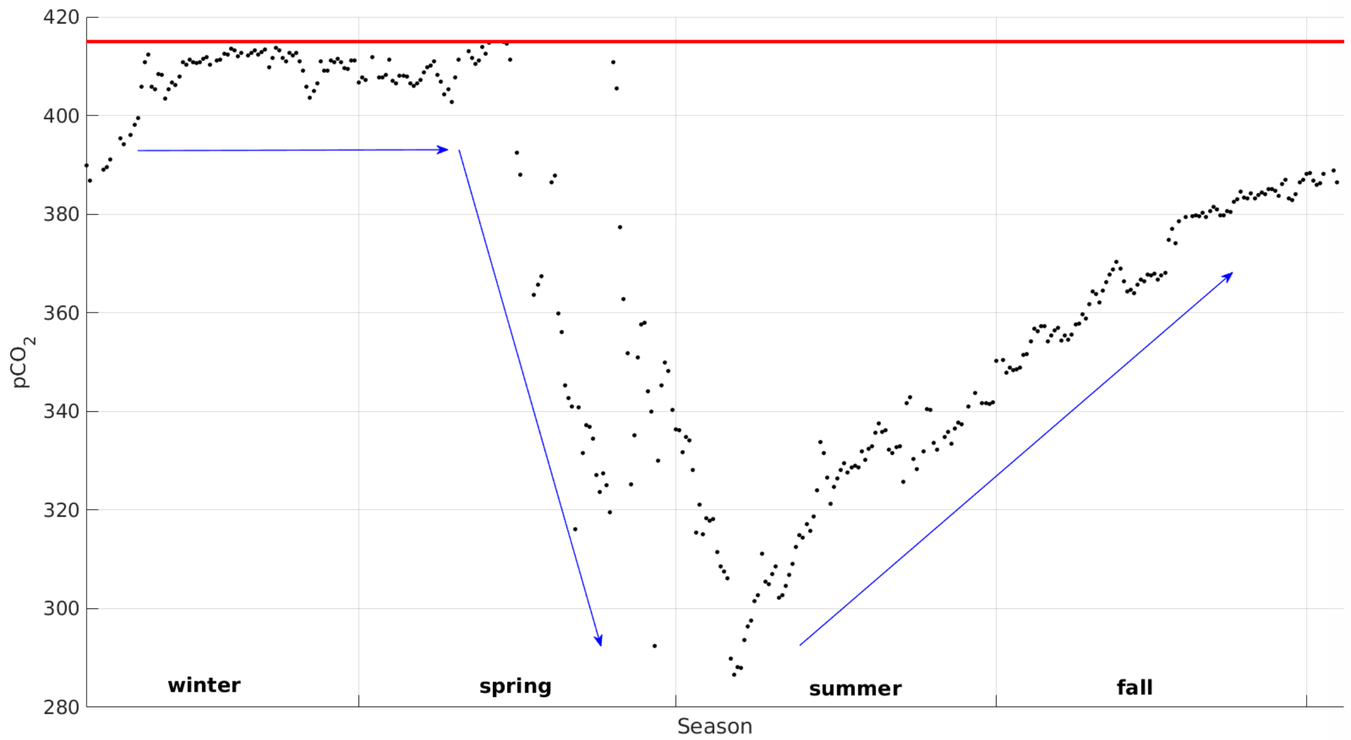
Schematic of seasonality in the Central Labrador Sea.

SEASONALITY

The Labrador Sea primarily absorbs CO_2 from the atmosphere year-round, but the quantity absorbed varies throughout the seasons. Similar to the seasonal changes we are used to seeing on land, the ocean also experiences periodic transformations throughout the year. During the cold winter, in the same way that there are no leaves on our trees, there is also almost no phytoplankton to consume CO_2 in the ocean. At this time, surface and deep waters are also well mixed and waters high in CO_2 come up from the depths, increasing the pCO_2 of the surface ocean and leading to a decreased flux of CO_2 from the atmosphere to the ocean.

In the spring, as the flowers bloom on land, phytoplankton also bloom in the ocean, consuming CO_2 at a high rate and decreasing pCO_2 in the surface ocean. This is the season when fluxes of CO_2 from the atmosphere intensify. These fluxes grow stronger through spring and summer, reaching their maximum around mid-summer. In autumn, as waters grow colder once again, phytoplankton populations begin to decrease. In the same way that the leaves change color, the ocean also starts to change again as pCO_2 begins to climb back up to the winter maximum and CO_2 fluxes into the ocean decrease again, stabilizing at a low winter absorption of atmospheric CO_2 until the next spring.

A complex interplay of opposing forces drives the changes in pCO_2 and CO_2 fluxes between the atmosphere and the ocean. Temperature, biological production, winds, ocean mixing, ocean currents, and the increase of man-made atmospheric CO_2 all affect these CO_2 fluxes simultaneously. As a result, there is a lot of variability in both space and time, most of which remains unobserved by our sensors.



Seasonality of pCO_2 in the Central Labrador Sea (average pCO_2 per day of the year). Red line indicates atmospheric pCO_2.

IMPORTANCE OF MORE OBSERVATIONS

More observations of pCO_2 in the surface ocean are necessary for a better understanding of how the absorption of CO_2 by the oceans is changing in space and time. We are on the right path; as our sensors improve, the number of pCO_2 observations for the entire global ocean is growing every year. However, some regions remain short on coverage of this essential variable. My work discusses the lack of pCO_2 data available for the Labrador Sea and focuses on increasing their number, gathering all the data that I can from this region to improve our estimates of this region's CO_2 absorption strength. The final part of my PhD will combine all available data with neural network algorithms to fill in the data gaps and map the distribution and variability of pCO_2 between 2000 and 2020.

With more observations, the techniques for filling the gaps in data coverage will improve drastically and so our understanding of what drives the pCO_2 variability will improve with it. Finally, improving our estimates for the Labrador Sea will lead to a better understanding of the carbon fluxes for the whole North Atlantic Ocean. ▶

This work was supported by NSERC-CREATE through the Transatlantic Ocean System Science and Technology (TOSST) program. Also supported by collaboration with the Ocean Frontier Institute (OFI).

Ricardo Arruda Monteiro da Silva, Chemical Oceanography

Originally from a small town in the countryside of Brazil, Ricardo is now a well-versed oceanographer. From biological oceanography and marine management during his bachelor's degree, to physical oceanography and biogeochemical modeling during his master's degree. After completing his master's, he worked as a marine technician. Currently, Ricardo is a PhD student in chemical oceanography focusing on observational data and oceanographic instrumentation concerning air-sea CO2 fluxes in the North Atlantic Ocean and measurements of $pCO2$ in the ocean surface. In his spare time, Ricardo enjoys swimming, computer gaming, photography, hiking, & camping.

DO I HEAR TROUBLE CALLING?

Finding whales and keeping them out of the fast lane

By Delphine Durette-Morin & Meg Carr

Right whale Catalog #3560 'Snow Cone' and calf, sighted December 18, 2021 just offshore of Ponte Vedra Beach, FL. Florida Fish and Wildlife Conservation Commission, taken under NOAA permit 20556-01.

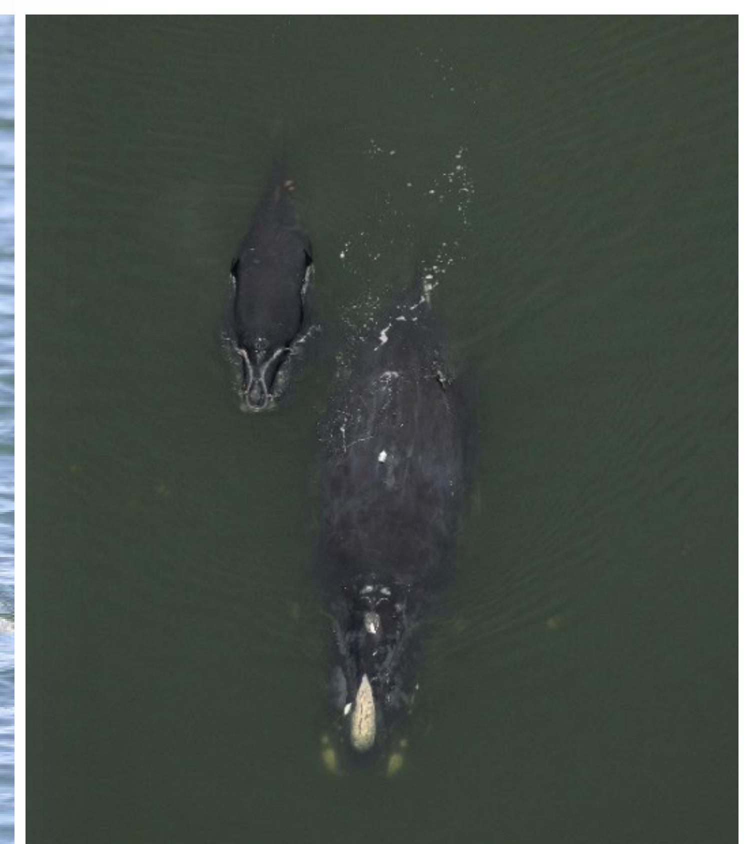
North Atlantic right whales (hereafter: right whales) are critically endangered and currently number around 336 individuals.

These whales travel along the east coast of North America, from calving grounds off the coast of Florida and Georgia, to northern feeding grounds extending from Cape Cod Bay northward to the Gulf of St. Lawrence (hereafter: the Gulf). Since 2010, right whales have undergone a population decline fueled by decreasing birth rates and high rates of human-caused mortality in the forms of vessel strikes and fishing gear entanglements; near the ocean's surface, encounters with ship traffic put these whales at risk any time they breathe or rest, while ocean noise and a web of fishing lines attached to crab and lobster pots make the water column unsafe.

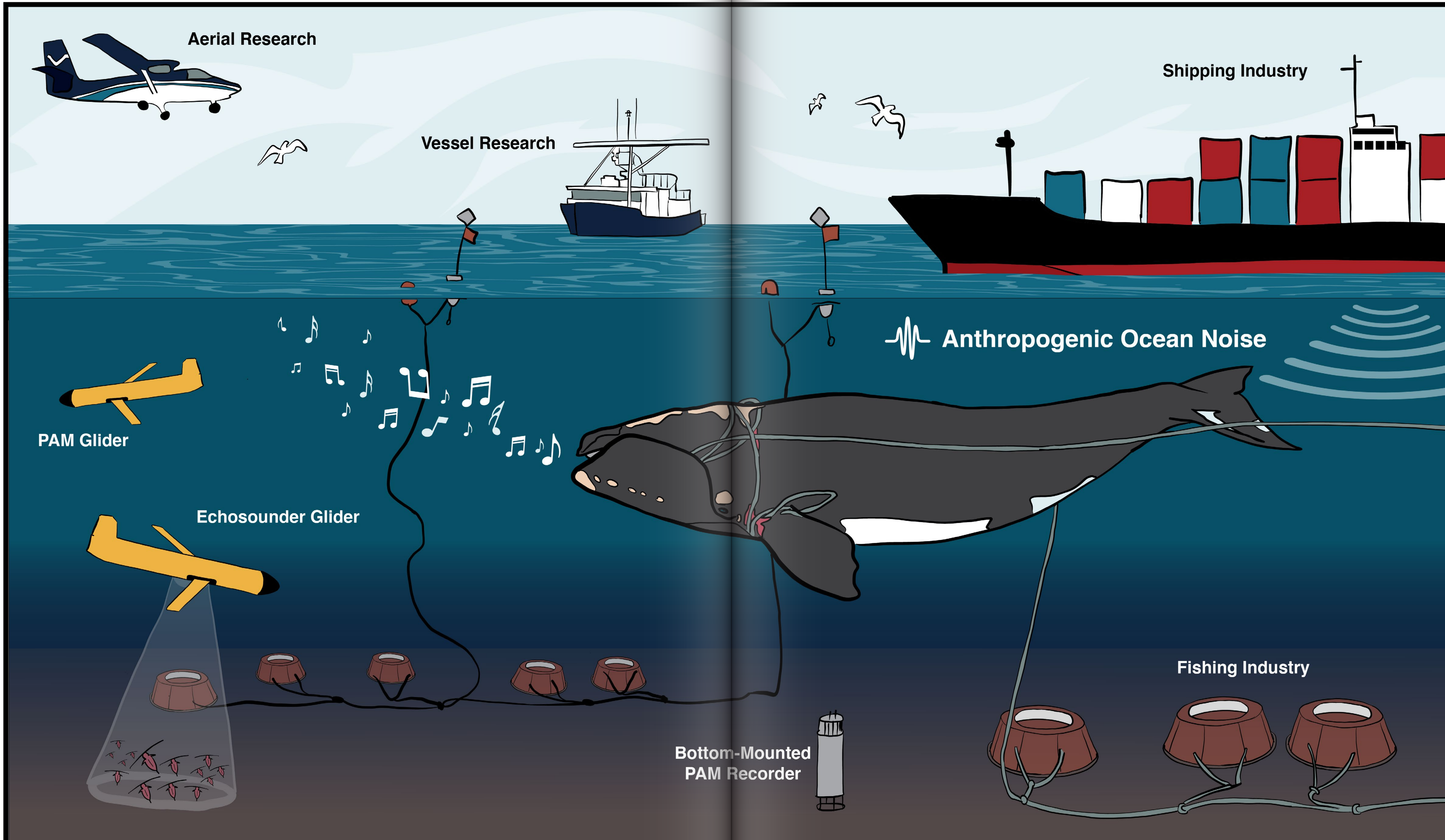
Using photographs amassed over a whale's lifetime, researchers have been able to piece together the life histories of some right whales. One example is the story of a whale named Punctuation, numbered #1281. Punctuation was named for the unique set of small scars on her head that look like dashes and commas. Between her first sighting in 1981 and final sighting in 2019, she was photographed 250 times along the east coast of North America. Scar analysis allowed scientists to determine that she suffered from five separate entanglements during her life and three vessel strikes, the last of which ended her life at the age of 38+. Throughout her life, Punctuation had eight calves and two grand-calves but five of her calves and both of her grand calves have died either as a result of vessel strikes, fishing gear entanglements, or have disappeared and are presumed dead. Unfortunately, the harrowing history of Punctuation is not exceptional among right whales, as many individuals have similarly tragic stories.
Stories like Punctuation's could be avoided with more effective management of anthropogenic risks. Current management strategies include speed limits, re-routing of vessels, excluding fishing from certain areas and changes to fishing season start and end dates to create less overlap between fisheries and whales. Well-balanced management strategies consider how to achieve effective whale protection, while also reducing unnecessary negative impacts to shippers and fishers, such as increased operating costs due to longer shipping routes or shortened fishing seasons. The Taggart lab has used acoustics, oceanography, and risk analysis with the goal of providing better protection for right whales. In this article, we will discuss several projects that our lab has and is working on: assessing right whale distribution, informing dynamic risk management, and assessing vessel-strike risk.

RIGHT WHALE DISTRIBUTION

Characterizing animal distribution can be problematic when the species in question are difficult to study, such as large marine mammals. Most marine mammals are migrating species, covering vast distributional ranges over 1000s of kilometers. To date, no technology has been developed to efficiently tag individual right whales without elevated health risks to this Species At Risk Act (SARA) species. Visually tracking the whales is another alternative, but these animals spend the majority of their time under water, out of sight, and when they come to the surface to breathe or rest, they blend with their surrounding environment, making them difficult to detect. Furthermore, visual surveys remain costly as



Left: The right whale, Punctuation (Catalog #1281), rests with her head just above the surface near Fernandina Beach, FL. Photo Credit: Florida Fish and Wildlife Conservation Commission, taken under NOAA research permit #15488. **Right:** Punctuation and her 2016 calf swimming side-by-side near Cumberland Island, GA. Photo Credit: Florida Fish and Wildlife Conservation Commission, taken under NOAA research permit #15488.


Aerial Research
Vessel Research
Shipping Industry
Anthropogenic Ocean Noise
PAM Glider
Echosounder Glider
Fishing Industry
Bottom-Mounted
PAM Recorder

Necropsy team surrounding Punctuation as they gather samples to determine cause of death. Photo credit: Nick Hawkins.

they require observations from a ship or plane, are dependent on sufficient daylight, as well as calm weather and sea state.

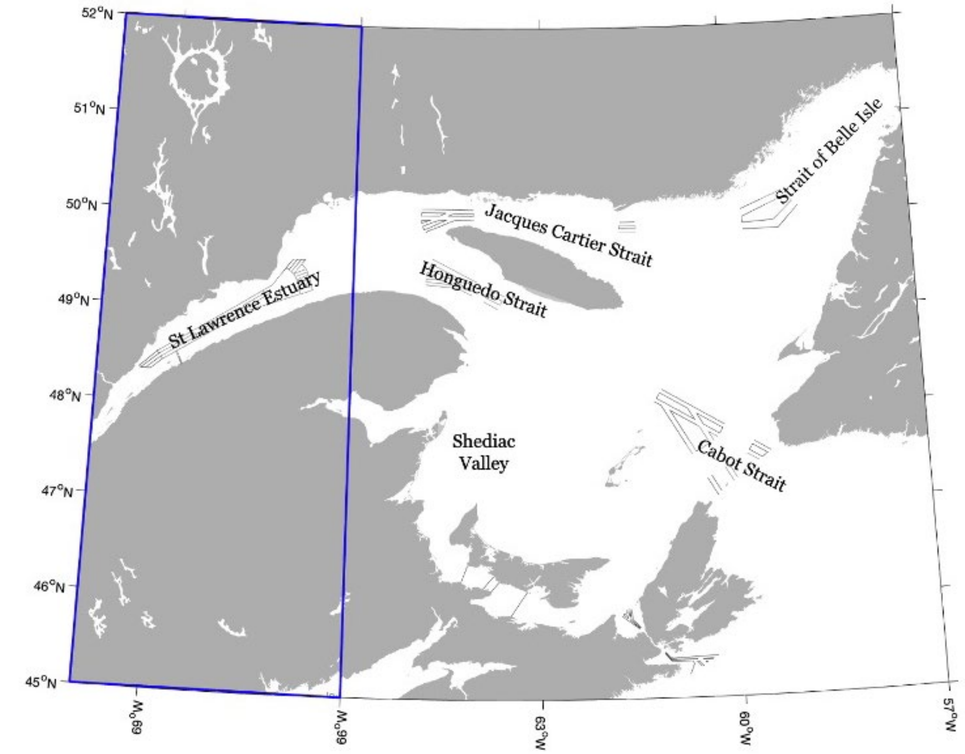
Since 2015, the number of visual monitoring surveys have drastically increased in Canadian waters but efforts have remained largely focused on areas where whales are known to occur and aggregate in larger groups (namely, in Roseway Basin, Grand Manan Basin and in the Gulf). This is an effort to maximize whale sightings despite the challenges of limited resources and variable weather conditions. Unfortunately, because of this, right whale distribution remains poorly described in the rest of Atlantic Canadian waters.

PASSIVE ACOUSTIC MONITORING

Delphine Durrette-Morin

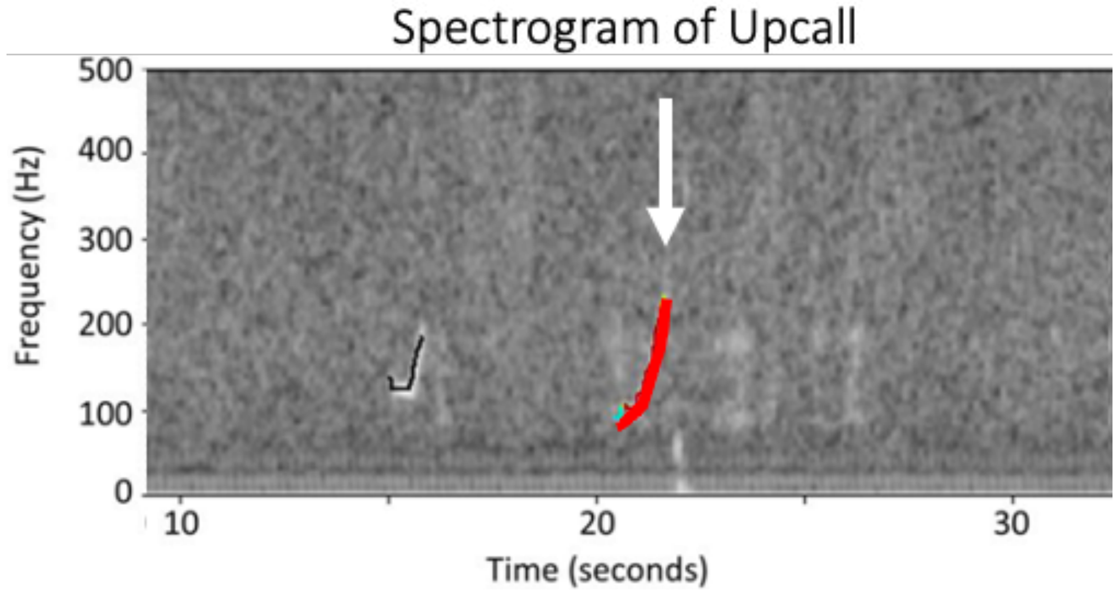
Passive acoustic monitoring provides an alternative option to study the whale's distribution over large spatial and temporal scales. Simply, an underwater microphone, called a hydrophone, is placed at a fixed location or on a mobile platform to record continuously for a period of time, hence the term "passive acoustics". These recordings can later be analyzed to identify sounds that are species specific. For example, right whales can be detected using their species-specific sound, known as the upcall. When an upcall is present in a recording, we know there was at least one right whale near the recorder at that time. Recordings are processed using software that automatically highlights any potential upcall, reducing the manual labor required–but don't be fooled, there's still plenty of data for analysts to review. Analysts validate each potential upcall aurally and visually, with the use of a spectrogram, a visual representation of sound in the time and frequency domain. Only upcalls that have been verified by an analyst are used in our analysis.

Using a passive acoustic monitoring network, I obtained a large-scale perspective of right whale distribution across Atlantic Canadian waters, from the Bay of Fundy to the Labrador Shelf. This network consisted of numerous hydrophones deployed by different agencies between 2015 and 2017. The hydrophones did not cover all possible areas in Atlantic Canada, yet the results provide insights into right whale distributions in many data-deficient areas. For example, most of the right whale acoustic detections were constrained to recorders located in temperate and subarctic latitudes. This tells us that right whale distribution may not extend as far north as their prey, copepods of the Calanus species. Right whales were also detected in the Cabot Strait, an area of great conservation concern with little to no monitoring effort. The Cabot Strait is one of the only two entry points into the Gulf for both whales and marine transport



Map of the Gulf of St. Lawrence (no outline) and St. Lawrence Estuary (blue outline). Grey lines and polygons indicate the location of vessel traffic separation schemes (TSS).

> "Right whales can be detected using their species-specific sound, known as the upcall."
>
> - Delphine Durette-Morin, Dalhousie University



Left: Spectrograph of a typical North Atlantic right whale upcall. **Bottom right:** Delphine records data and communicates with the captain during a right whale survey. Photo provided by New England Aquarium and Dalhousie.

and this overlap creates an area of high risk for ship strikes, highlighting the need for monitoring and risk mitigation. Of course, knowing where whales occur is only the first step, but it can help inform the allocation of local management efforts.

DYNAMIC MANAGEMENT

Delphine Durrette-Morin

Two types of spatial and temporal management are used in the gulf to protect right whales. Static management mitigates risk in defined, fixed areas over longer periods of time while dynamic management regulates risk across smaller scales of time and space. In the Gulf, dynamic management restricts marine activities (such as fishing and shipping) at specific times of the year and in areas that pose a risk to whales–otherwise marine activities are allowed. It works by restricting marine activity after an observation of a whale has been made and therefore requires knowledge of species distribution on a more localised scale.

In 2017, twelve right whales died in a mortality event resulting from ship strikes or fishing gear entanglements in Canadian waters, leading the Canadian Government to implement fishery and shipping restrictions for right whale protection. These measures are altered annually as more information about the distribution of right whales is gathered. For example, in 2020, fishery-area closures and speed restrictions zones were triggered by a visual or acoustic detection of a right whale. This marked the first year acoustic detections were used in management restrictions, increasing Canada's ability to efficiently monitor for the presence of the species!

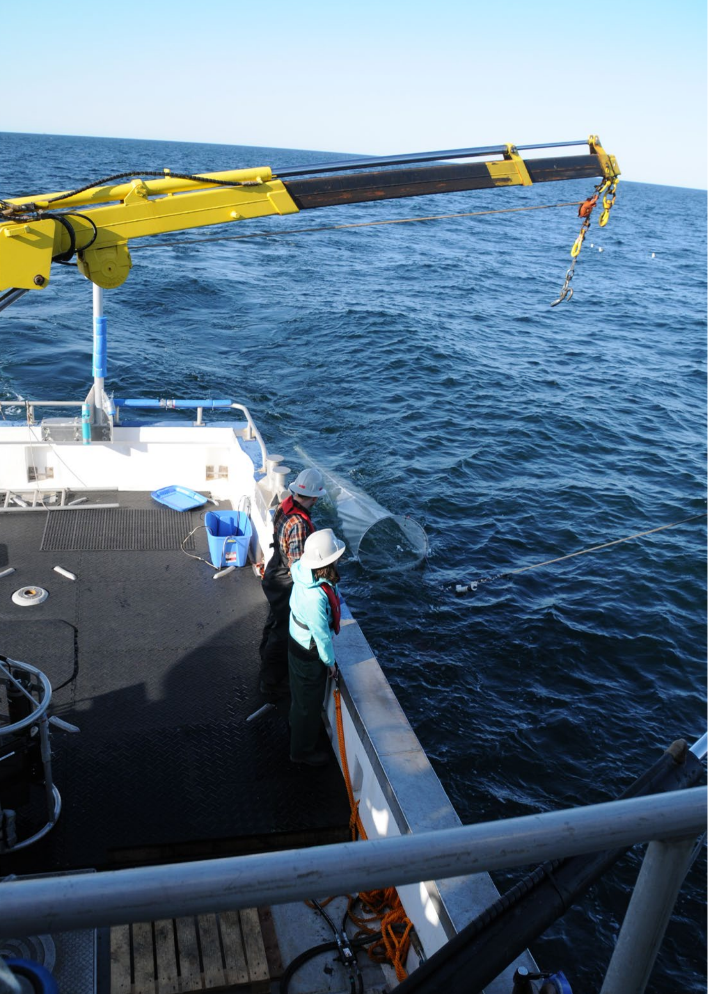
ACOUSTIC GLIDER SURVEYS

Delphine Durrette-Morin

Since 2014, gliders have been used to monitor right whales in Canadian waters. Hydrophones are mounted on the glider and as it moves through the water column, the hydrophones listen for the presence of whales. An automated detector onboard the glider provides us with right whale detections in near real-time via satellite communication (see Current Tides Volume 4). However, even though gliders monitor continuously, they travel slower than the planes or vessels visually monitoring, so it is important to strategically allocate glider effort for an efficient survey.

A variety of factors should be considered when designing an efficient survey. Some examples include the duration, location, and spatial coverage of the survey (e.g. survey a small area continuously or cover as much ground as possible while spending very little time at each location). Another important thing to consider is the probability of encountering a whale. If the glider goes where whales don't occur, the survey will be less efficient.

Taking all of these factors into consideration, I designed a glider survey to efficiently



Meg and Hansen prepare to retrieve a plankton sample in the Gulf of St. Lawrence. Photo provided by New England Aquarium and Dalhousie.

> “Vessel-strike risk can be mitigated in two ways: by separating vessels and whales in space and time or by reducing the speed of vessels.”
>
> - Meg Carr, Dalhousie University

monitor an area for the presence of right whales to inform dynamic management. This survey took place in the Gulf in the summer of 2020 and our whale detections led to dynamic management closures for multiple fishery areas. This represented the first time an acoustic glider informed dynamic management–a huge step in the development of tools for whale conservation! These efforts highlight the potential and efficiency of the glider as a suitable monitoring tool for dynamic management and while we still have a long way to go before whales are safe from human induced risks, studies such as these are crucial in advancing our ability to monitor and conserve these species.

VESSEL-STRIKE RISK

Meg Carr

The main focus of my research is to inform conservation initiatives meant to reduce vessel-strike risk to endangered whales in the Gulf and Saint Lawrence Estuary. My work compares the distribution of vessel-strike risk across space and time, and among different management strategies to establish a protocol for testing their effectiveness. Vessel-strike risk can be mitigated in two ways: by separating vessels and whales in space and time, so that a strike is less likely to occur, or by reducing the speed of vessels to decrease the likelihood that a strike is lethal. Current management includes a combination of mandatory and voluntary speed limits. These reduce the likelihood that a strike will be lethal, but do not reduce the likelihood of a strike occurring.

For example, the near real-time glider technology used by Delphine to inform fishery closures was also used to inform dynamic slow-down zones for vessels in the Cabot Strait as part of a collaborative effort with Transport Canada (TC) and the Davies Lab at the University of New Brunswick, led by Dr. Kim Davies. Within the first 24-hours of the glider being in the water, dynamic slow down zones were triggered and these slow down restrictions were then active for 15 days.

acoustic detection of right whales in the Gulf as well as the deaths of seventeen right whales, the Government of Canada established a static management zone in the western Gulf. Within this zone, vessels more than 20 meters long are required to travel at a maximum of 10 knots (kt). The timing of the slowdown changes annually but aims to encompass the time of year in which right whales are present in the Gulf. In addition to mandatory speed limits, a voluntary speed limit zone was established in the Cabot Strait in 2019. These speed limits aim to reduce vessel-strike risk to right whales and are modified annually with the goal of improving their effectiveness. As part of my research, I will assess the 2017, 2018 and 2019 speed limits to estimate compliance, analyse vessel behaviour, and look at how vessel-strike risk varies in space and time.

Catalog #1245 “Slalom” and calf spotted off South Carolina., November 24, 2021. Photo credit: Clearwater Marine Aquarium Research Institute & USACE taken under NOAA permit #20556-01.

Left: Meg and Hansen process a plankton sample collected near feeding right whales. **Right:** An immature black-legged kittiwake spotted during a cetacean survey. Photos provided by New England Aquarium and Dalhousie.

COMPLIANCE

Meg Carr

Risk reduction schemes, like the speed limits in the Gulf, can only be effective if mariners exhibit compliance. Since 2017, forty-four violations of the mandatory Gulf speed restriction have been reported by TC, resulting in $311,550 of collected fines. However, compliance rates vary depending on how vessel speed data is collected. Therefore, I will compare several methods of speed determination when I assess compliance to find the best way to calculate speed and enforce speed limits.

A preliminary study found that only a disappointing 33% of vessels complied with the voluntary 10 kt maximum speed and there has been low to nonexistent compliance with voluntary measures aiming to reduce vessel-strike risk to right whales outside of the Gulf. Part of my research will compare compliance rates among voluntary and mandatory speed limits in the Gulf and across time to determine the effectiveness of both measures.

VESSEL BEHAVIOUR AND DISTRIBUTION OF VESSEL-STRIKE RISK

Meg Carr

Variability in vessel traffic patterns, particularly in the routes used, also impacts the effectiveness of static vessel-strike mitigation strategies. By analysing traffic in the Gulf, I will determine which changes in vessel patterns are a direct result of speed limits, and which are typical seasonal changes. To accomplish this, I plan to characterize seasonal vessel patterns during years with and without speed restrictions. My goal is to identify trends in vessel routes, densities, and speeds that can be used to inform future management techniques.

Current mitigation strategies and vessel-strike studies generally focus on large and faster-moving vessels, but smaller and slower vessels pose risks to whales as well. My research considers both large vessels, which are required to comply with the 10 kt speed limit, as well as smaller fishing vessels which were exempt from this rule until 2020. By doing this, I'll be able to identify regions of elevated risk and quantify changes in risk due to conservation initiatives, such as the 10 kt speed limit.

BIG PICTURE

As climate change continues to alter ecosystems and increase water temperatures across the North American seaboard, many species distributions may be altered, including that of the right whale. It is imperative that Canada prepares for an increase in whale presence in our waters in the event that their distribution continues to shift north.

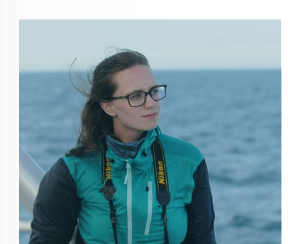
Humans and whales can coexist, but anthropogenic threats need to be reduced if right whales are to survive. Canadian waters contain a high level of risk due to important marine routes and fishing industries, but the utilization of acoustic detections of whales to inform both static and dynamic management is a big step in the right direction. Continued development of management strategies that protect both right whales and the marine commerce industry are imperative.

Testing the effectiveness of risk management is critical to ensure we are actually protecting whales. Therefore, a responsive and adaptive management strategy is key for protecting highly mobile species, such as the right whale. Our lab and others are trying to tackle this from as many angles as possible. The acoustical, oceanographic, and risk analysis tools used by our lab to study right whales can be applied to other species, in other areas, and can even be used as a framework for analyzing different sources of risk, meaning they are relevant to conservation initiatives beyond our own research. ▶

Delphine was supported by the Marine Environmental Observation, Prediction and Response Network (MEOPAR) and the Nova Scotia Graduate Scholarship (NSGS). and thanks all those at Jasco Applied Sciences, DFO-Maritimes and Newfoundland regions, and the CEOtr glider group who contributed data for these studies! Meg thanks all the groups who contributed data to these projects, including: the North Atlantic Right Whale Consortium, Anderson Cabot Centre for Marine Life at the New England Aquarium, Canadian Whale Institute, Mingan Island Cetacean Study, National Atmospheric and Oceanic Administration Northeast Fisheries Science Center, Transport Canada, Fisheries and Oceans Canada, and Exact Earth.

Delphine Durette-Morin

Growing up with her name, Delphine was destined to dream of studying dolphins and other marine mammals. She moved to Halifax where she completed a combined BSc in Marine Biology and Oceanography and a MSc in Oceanography at Dalhousie University. Today, Delphine is an Assistant Scientist at the Canadian Whale Institute, where she focuses on habitat stewardship and whale disentanglement. At home, Delphine is often found experimenting in the kitchen with new recipes (lately some exciting ferments!), outside gardening, or on a beach taking in the sunsets.



Meg Carr

Meg grew up knee-deep in the mud flats on Cape Cod and hasn't left the seaside since. It was only natural for her to pursue her interests at the University of New Hampshire where she completed her BSc in Marine, Estuarine, and Freshwater Biology, and continue pursuing her passions as a PhD candidate at Dal. As an avid outdoors-person, Meg loves canoeing, hiking, camping, and dogs. She enjoys trying out pastry recipes that are way too complicated and is rarely found without a mug of tea in her hand.

THE MYSTERY OF THE MISSING CO_2

Using transient tracers to estimate anthropogenic carbon concentrations in the Central Labrador Sea

By Lorenza Raimondi

Photo by Benjamin Richaud.

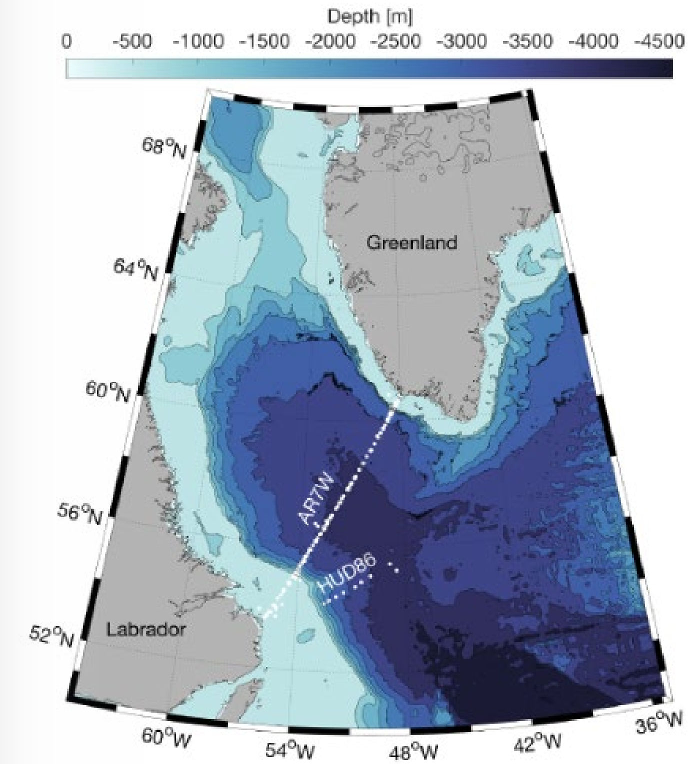
Today, I am going to bring you on a detective journey. But first, let's take a deep breath: inhale....exhale...

You probably already know that you have exhaled into the atmosphere the carbon dioxide (CO_2) that your body produces as waste. It is estimated that every person takes about 20,000 breaths a day! That is a lot of CO_2. However, since the start of the Industrial Revolution in roughly 1780, humans have contributed to the increase of CO_2 in the atmosphere primarily by heating their houses, producing cement, and flying around the world.

It has been estimated that of all the CO_2 emitted by humankind (called anthropogenic CO_2 or C_{ant}), only half remains in the atmosphere. So where did the other half go? The land biosphere (i.e., trees and plants) and the oceans represent the two "boxes" in which C_{ant} is stored for hundreds of years, therefore contributing to lowering the atmospheric CO_2 concentrations.

When CO_2 enters the ocean, it combines with water molecules to form carbonic acid. This weak acid immediately dissociates, releasing

A sunny day in the Labrador Sea aboard the R.V. Celtic Explorer. Photo by Madeline Healey.



Map of the Labrador Sea. Colour contours show depth of the ocean bottom (bathymetry), white dots represent stations where samples of CFC-12 were collected over thirty years on board the CCGS Hudson.

hydrogen ions (H^+) which decrease the pH of the seawater. This process, called "ocean acidification" (OA), has decreased the average pH of the ocean by ~0.1 units since the beginning of industrialization. These pH changes might seem very small to us, but this increase in acidity is detrimental to many shelled marine organisms (e.g., crustaceans and molluscs). To make matters worse, the ability of the ocean to uptake CO_2 decreases as more CO_2 enters the ocean, meaning that a greater amount of CO_2 will remain in the atmosphere in the future, contributing even more intensely to global warming.

Therefore, if we are to understand the ecological and climatological impacts of CO_2, it is crucial to estimate how much has been sequestered by the ocean. Whereas measurements of C_{ant} in the atmosphere are relatively easy to perform, measuring C_{ant} in the land biosphere and oceans is quite challenging. Given a choice between land and the ocean, I will always choose the latter. So, today we embark on a detective journey to find out how much C_{ant} is stored in the ocean, specifically in a basin called the Labrador Sea.

THE SCENE OF THE CRIME

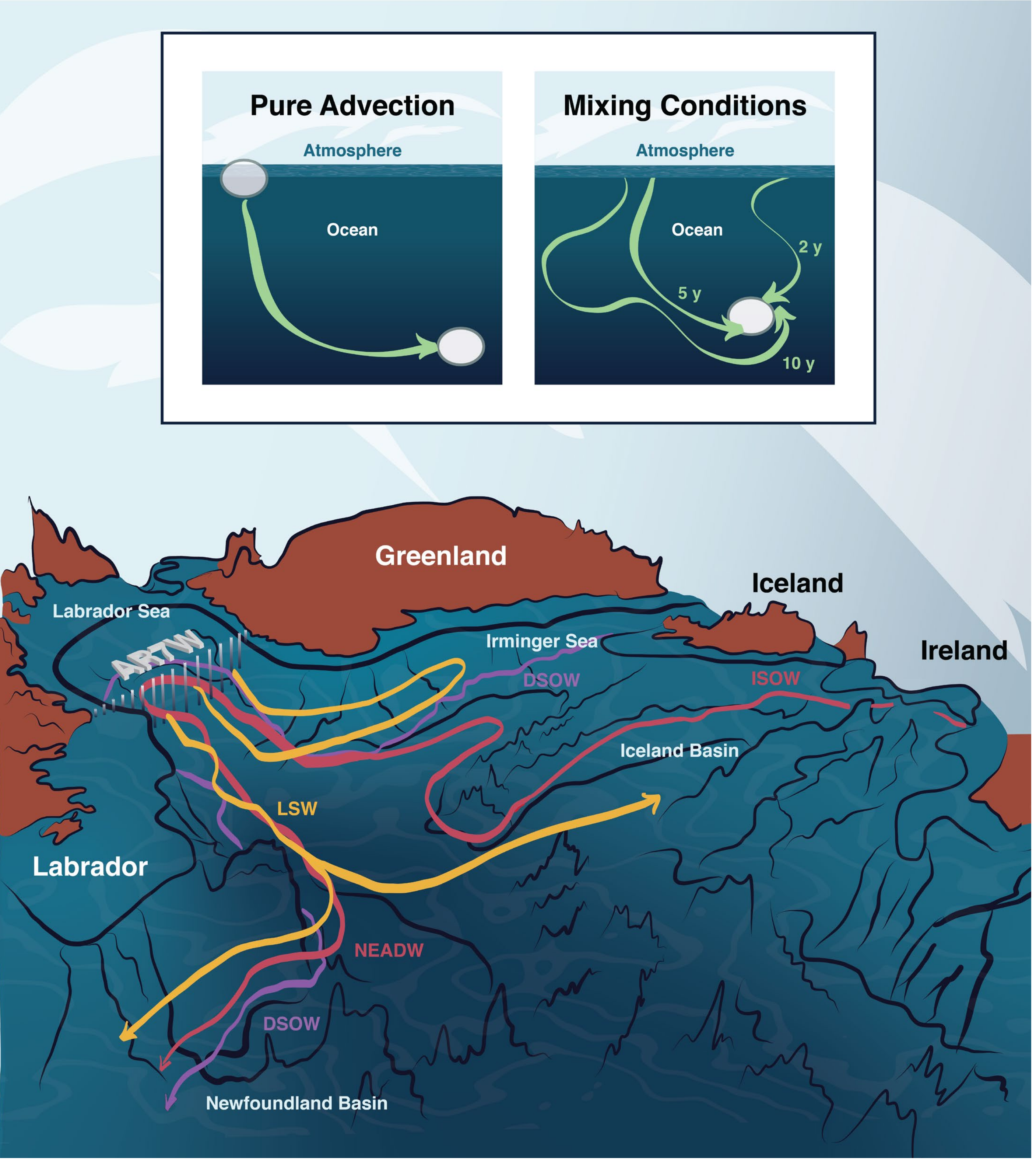
The ocean breathing

This might seem strange, but the oceans breathe too! While their breathing is quite different from our own, the oceans, too, take up and release gases. Generally, they take up (inhale) CO_2 at high latitudes (polar and subpolar regions) and release it (exhale) at low latitudes (tropical and sub-tropical regions). This "breathing" is primarily due to the oceans' circulation and so-called ocean "ventilation".

The Labrador Sea: An oceanic highway

During wintertime, the surface of the ocean loses heat due to strong winds. This heat-loss makes the surface water very cold and leads to the formation of sea ice at high latitudes. When ice crystals form from seawater, salt is left behind and the surrounding water becomes saltier. The combination of low temperatures and high salinity leads to an increase in seawater density (i.e., the water becomes "heavier"). Due to this increased density, the surface water moves deeper and deeper in the water column. This is the origin of the "thermohaline circulation", a circulation pattern controlled by changes in temperature (thermo) and salinity (haline).

While deep water formation occurs in several high latitude regions, I study the Labrador Sea, a semi-enclosed basin between Canada and Greenland. Since the 1930s, researchers at the Bedford Institute of Oceanography (Halifax, Canada) have been studying the formation of deep water in the Labrador Sea. Their long-term data reveals that surface water in this basin can sink between 500 to 2400 meters (m) depth due to the density changes mentioned above. Considering that the process of deep water formation only occurs between January and March, this is quite astonishing!



Schematic of principal water masses' circulation in the North West Atlantic. LSW Labrador Sea Water; DSOW Denmark Straight Overflow Water; ISOW Iceland Scotland Overflow Water; NEADW North East Atlantic Deep Water. Readapted from Yashayaev, I. and Clarke, A., 2008. Evolution of North Atlantic water masses inferred from Labrador Sea salinity series. Oceanography, 21(1), pp.30-45. **Inset:** Schematic of the transit time (or age, in years; y) of a water sample. Left panel shows the simple movement of a water mass from point A to B. Right panel represents ocean mixing, where water in one location is composed of many water parcels coming from different sources and taking different pathways.

But how is all of this important to solving our mystery? When surface water begins to sink, it carries everything it contains into the ocean interior, including the C_{ant} "inhaled" by the surface ocean! If the thermohaline circulation did not exist, C_{ant} would take many years to "move" from the surface to the deep ocean. Thanks to this

Left: Dalhousie Oceanography graduate students on Research cruise in the Labrador Sea. **Right:** CTD Rosette being deployed at sea. Photos by Madeline Healey.

circulation pattern, gases only take a few months to reach deep layers. This is why I like to call locations like the Labrador Sea *oceanic* highways!

THE TRACE-EVIDENCE COLLECTION KIT

As I mentioned, C_{ant} is very hard to measure in the ocean. This is primarily because there is no easy and practical technique to distinguish between naturally-occurring and human-produced CO_2, which is present in much smaller concentrations than the former (one available technique uses carbon isotopes, as described by Stephanie Mellon in Current Tides Volume 4).

So how can we find out how much C_{ant} is in the Labrador Sea if we cannot even measure it? It turns out, C_{ant} is not the only gas transported into the ocean interior. Some of the other gases transported are exclusively produced by human activities, have no natural counterpart, and analytical procedures have been developed to accurately measure their concentrations. These characteristics make them useful substitutes to track the path of C_{ant} in the ocean.

The imitation game

To track C_{ant}, I use dichlorodifluoromethane (commonly referred to as Freon-12 or CFC-12). Even though the use of CFC-12 and other freons is now restricted, you have probably heard of the environmental problems it caused. Ever heard of the ozone hole? Thank CFC-12. Since the early 1930s, CFC-12, used as refrigerant in household appliances and a propellant in spray bottles, has been emitted to the atmosphere in known concentrations, causing the thinning of the ozone layer. The silver lining, for us at least, is that CFC-12 has made its way into the oceans in a similar way to C_{ant}. Therefore, when we find CFC-12 in the Labrador Sea, we can use it to approximate C_{ant}.

Following the traces

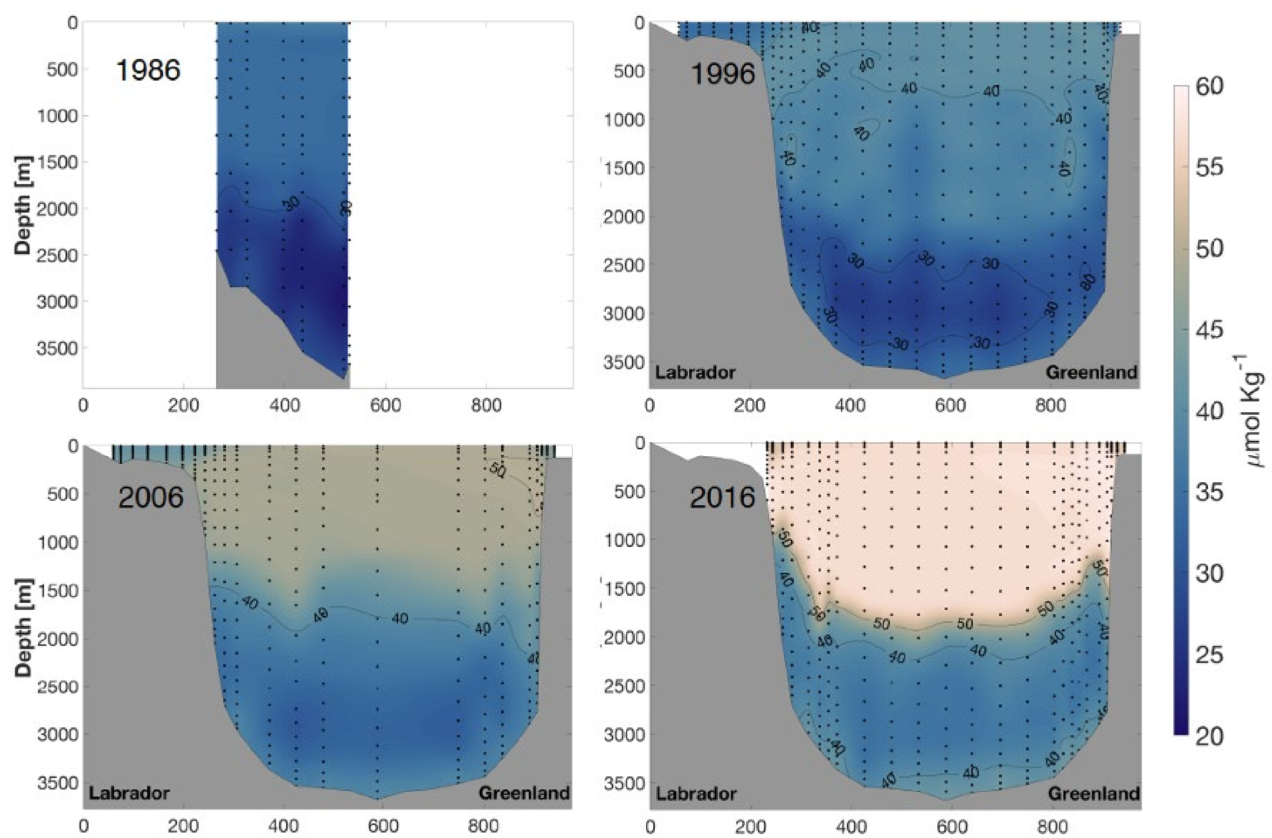
Every year, we take seawater samples at different depths and locations in the Labrador Sea. The CFC-12 concentrations are then measured using an instrument called a gas chromatographer.

We assume that the concentration of CFC-12 in the water has not changed since it was last in contact with the atmosphere, and knowing the atmospheric history of CFC-12, we can reconstruct how long that water took to move from the surface to the depth at which our sample was collected. The time elapsed is called "transit time" or "age" of the water.

Unfortunately, a parcel of water does not simply move from point A to point B. Instead, it mixes with other water parcels, changing the original concentrations of CFC-12. Therefore, the water we sample does not have a single age, but rather many ages due to the mixing of different water parcels transported from different locations. Using mathematical equations, we can represent this mixing, and thus estimate the transit time.

Similar to CFC-12, researchers have performed measurements of atmospheric CO_2 since 1958 (a record known as the "Keeling Curve"). By removing the estimated pre-industrial value of CO_2 in the atmosphere (280 parts per million [ppm]) from these values, we can obtain a yearly record of atmospheric C_{ant}.

Section plots of C_{ant} concentrations along the AR7W line over four years. The Labrador coast is to the left and the Greenland coast to the right. The plots show the progressive increase of C_{ant} concentrations and the deepening of its signal across the three decades of observations. Note that the 1986 plot shows estimates based on CFC-12 sampled at stations along a line positioned slightly to the south of the AR7W line (top left), hence the different bottom.



Collecting a CFC-12 water sample from a CTD rosette. Photo by © Christian Clauwers.

Putting the evidence together

Now we have two very important pieces of information: the age of the water we sampled and the atmospheric C_{ant} concentrations. Assuming that in wintertime, the air above Labrador Sea and the surface water are in equilibrium (they have the same amount of C_{ant}), we then also have a record of C_{ant} concentrations in the surface water.

For example, if we collected a water sample in 2020 that is 10 years old, this means that it was last in contact with the atmosphere in 2010. We can take the atmospheric concentration of CO_2 in 2010 (389 ppm), remove the pre-industrial signal (280 ppm) and obtain the concentration of C_{ant} in our water sample when it was last in contact with the atmosphere (109 ppm)!

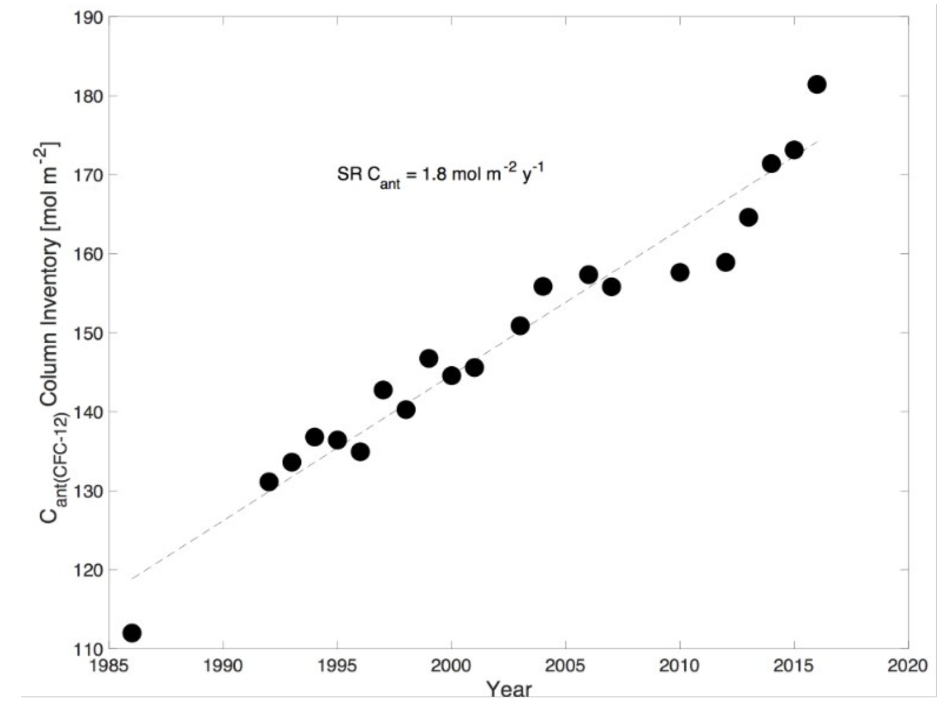
If we do this for all water samples for which we have CFC-12 measurements, we can estimate C_{ant} concentrations across the Labrador Sea. I applied this technique to the long-term observations in the Labrador Sea between 1986 and 2016, allowing me to understand how the distribution and concentration of C_{ant} has changed over these three decades. Moreover, these annual estimates of C_{ant} offer the opportunity to identify factors that affect the amount of C_{ant} stored in the Labrador Sea every year. We observed that C_{ant} concentrations have dramatically increased over time and that the C_{ant} signal can be detected even at the bottom of the Labrador Sea, at around 3600 m depth.

"C_{ant} concentrations have dramatically increased over time and can be detected even at the bottom of the Labrador Sea, at around 3600m depth."

- Lorenza Raimondi, Dalhousie University

This work was supported by the Canada Excellence Research Chair in Ocean Science and Technology (CERC.OCEAN), the Ocean Frontier Institute (OFI), the NSERC CREATE Transatlantic Ocean System Science and Technology (TOSST) program, the Ventilation, Interaction and Transports Across the Labrador Sea (VITALS) program and the Department of Fisheries and Ocean's Atlantic Zone Off-Shore Monitoring program (AZOMP).

Photo by Nina Y. Golembek.



Column Inventory of C_{ant} in the central Labrador Sea between 1986 and 2016. The dashed line represents the trend and the slope of this line represents the storage (or accumulation) rate (SR).

SHEDDING SOME LIGHT ON THE MYSTERY OF THE MISSING CO_2

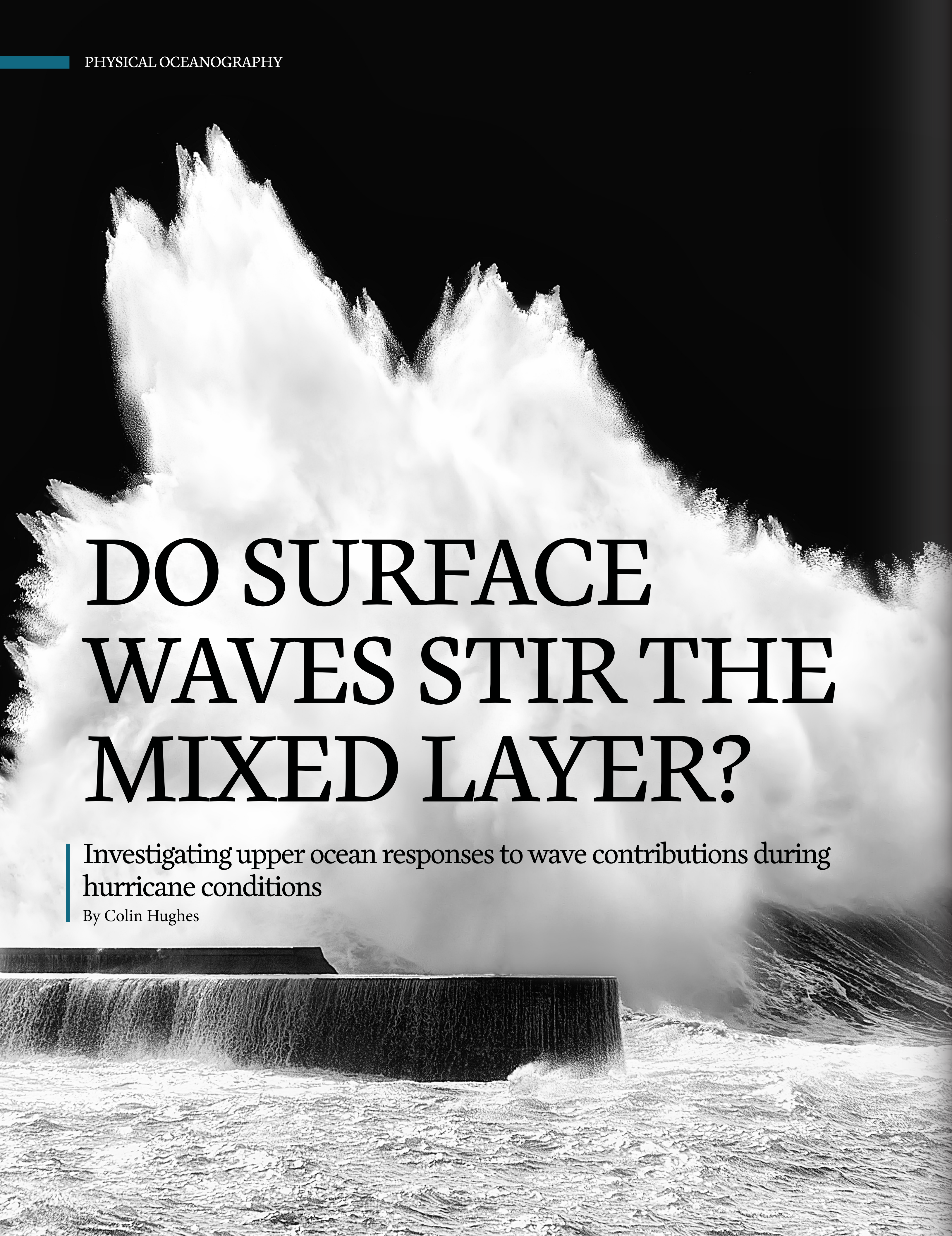
By summing all C_{ant} concentrations for one station in the central Labrador Sea, from surface to bottom, we obtain a water column inventory of C_{ant}. By comparing column inventories from different years, we can elucidate the pace at which the column inventory has changed over the past thirty years of observations. This rate is defined as C_{ant} storage rate (SR) or accumulation rate.

I found that C_{ant} increases at an average pace of 1.8 moles per square meter per year during the thirty-year observation period. This might seem like a very small number, but it is almost three times greater than the global average accumulation rate of C_{ant}! Therefore, potential future reductions of Labrador Sea uptake capacity will likely have a large impact on a global scale. My results are instrumental for the validation of numerical models that predict future scenarios of climate change.

The mystery of the missing CO_2 is now partially solved! There are still many questions to be answered: how fast are other regions of the ocean accumulating C_{ant}? What drives changes in the pace at which C_{ant} is accumulated in the Labrador Sea? But we can't solve all of Earth's mysteries in one day, so for now, we will have to save these questions for a later investigation. ▶

Lorenza Raimondi, Chemical Oceanography

Regardless of where she was living or what she was doing, the ocean has been a constant in Lorenza's life. It's no surprise that all her career choices have been dictated, directly and indirectly, by this one driving factor: uncovering the mysteries of the ocean. Lorenza is originally from Italy where she obtained both her Bachelors and Masters degrees. She recently completed a PhD in Oceanography at Dalhousie University where she worked with Dr. Doug Wallace and Dr. Kumiko Azetsu-Scott. Lorenza is now a Postdoctoral Fellow at ETH Zürich where she works with Prof. Dr. Núria Casacuberta Arola. When not in the lab, Lorenza can be found crafting (from painting to knitting, which she all does quite poorly…), cooking or enjoying some quality time with her partner Francesco and their son Totò.



DO SURFACE WAVES STIR THE MIXED LAYER?

Investigating upper ocean responses to wave contributions during hurricane conditions

By Colin Hughes

WAVE THREATS AND CONTRIBUTIONS TO HURRICANE INTENSITY

Wind-driven ocean surface waves caused by hurricanes result in massive destruction to human lives and coastal property. These waves can also be hazardous to off-shore structures, shipping, and recreational activities. This is because high winds from hurricanes and Nor'easters can lead to significant wave heights as tall as a five-story building. Some waves, known as rogue or freak waves, can even grow to more than twice this significant wave height. Such gigantic waves can occur when waves and currents meet from opposite directions.

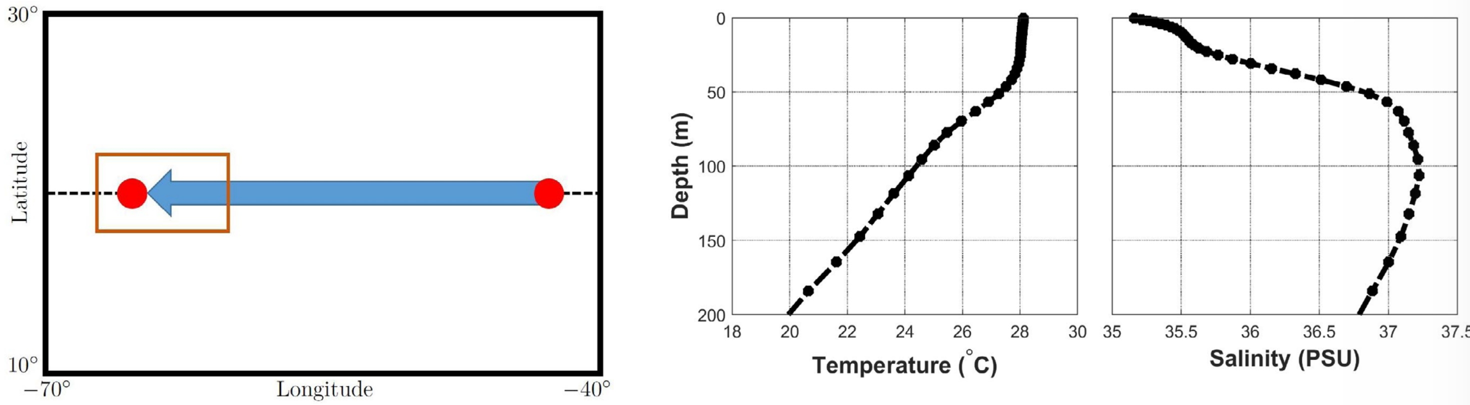
Ocean surface gravity waves are generated by wind. Wave size is positively correlated with the time and the distance over which the wind blows. Therefore, larger waves occur when wind blows for a longer period of time and over a further distance. Vertical mixing and horizontal circulation in the upper ocean (top 200 m in this case) change when surface waves interact with currents.

During hurricanes, interactions between wind, waves, and ocean currents contribute to changes in sea surface temperature (SST). Heat evaporating from the ocean fuels the formation and maintenance of hurricanes. Higher SSTs and thicker upper mixed layers can produce larger evaporative heat fluxes. Alternatively, cooler SSTs and thinner upper mixed layers weaken hurricanes or inhibit their formation. Waves further alter the distribution of heat in the upper ocean. For example, wave breaking enhances vertical turbulent mixing in the upper ocean and alters horizontal circulation. Thus, waves affect SST and in turn the available ocean heat necessary for hurricane formation and intensification. We should therefore include waves in hurricane models as this will likely improve forecasts.

HOW ARE WAVES INCLUDED IN HURRICANE MODELS?

Operational hurricane forecast models tend to ignore surface waves despite their impacts on upper ocean dynamics. In the simplest case, water particles move in circular loops (in deep water). However, particle speed decreases with depth, so the trajectories have open, rather than closed loops. These open loops lead to a net transport known as Stokes drift. Stokes drift interacts with currents to produce three different conservative wave effects on currents. The first conservative wave effect is Coriolis-Stokes forcing (CSF). CSF deflects the Stokes drift to the right (in the Northern hemisphere) as a result of the Earth's rotation. The second is the advection of tracers via Stokes drift. Tracers, such as temperature and salinity, follow the same trajectory as water parcels transported via Strokes drift. The third conservative wave effect is the large-scale wave-current interactions. This effect refers to the Stokes drift modifying currents over spatial scales

> "Wave breaking enhances vertical turbulent mixing in the upper ocean and alters horizontal circulation."
>
> - Colin Hughes, Dalhousie University



Left: Schematic of the idealized domain with the red dots showing the approximate initial and final locations of the hurricane storm center. The orange box represents the approximate location of the surface plots. **Right:** Initial vertical profiles of (left) temperature and (right) salinity in the upper 200 m taken from a tropical location in the North Atlantic.

that the models can directly resolve (1,000s of km). All of these conservative wave effects are included within the models that I work with.

Unfortunately, these models cannot resolve wave effects over spatial scales less than hundreds of metres, due to computational limits. However, this is where interesting physical phenomena develop! Over spatial scales of 10-100 m, the interaction between the Stokes drift and currents produces Langmuir circulation (LC). Langmuir circulation consists of vertical counter-rotating roll vortices (think of rows of paper towel rolls spinning in opposite directions) that includes both regions of a convergence of flow and regions of a divergence of flow at the surface. Surface convergence zones can be identified visually by the presence of debris streaks. Downwelling occurs at these regions of convergence between the vortices and reciprocal upwelling occurs at the regions of surface divergence. In reality, the vortices are not perfectly symmetrical, but often asymmetrical and unstable. Hence, the generalized term LC is often referred to as Langmuir turbulence (LT).

I sought to evaluate the importance of waves to the upper ocean circulation and temperature structure during hurricanes. To this end, I added parameterizations of wave breaking and LT to an existing coupled wave-circulation model. A coupled model, in essence, includes two different models: a spectral wave model and a circulation model. A spectral wave model describes the propagation of wave energy rather than individual surface waves. Ocean circulation models describe the propagation of ocean currents and scalar terms known as tracers. Coupling takes the wave and circulation models and enables communication between them with terms moving in one (one-way coupling) or both (two-way coupling) directions.

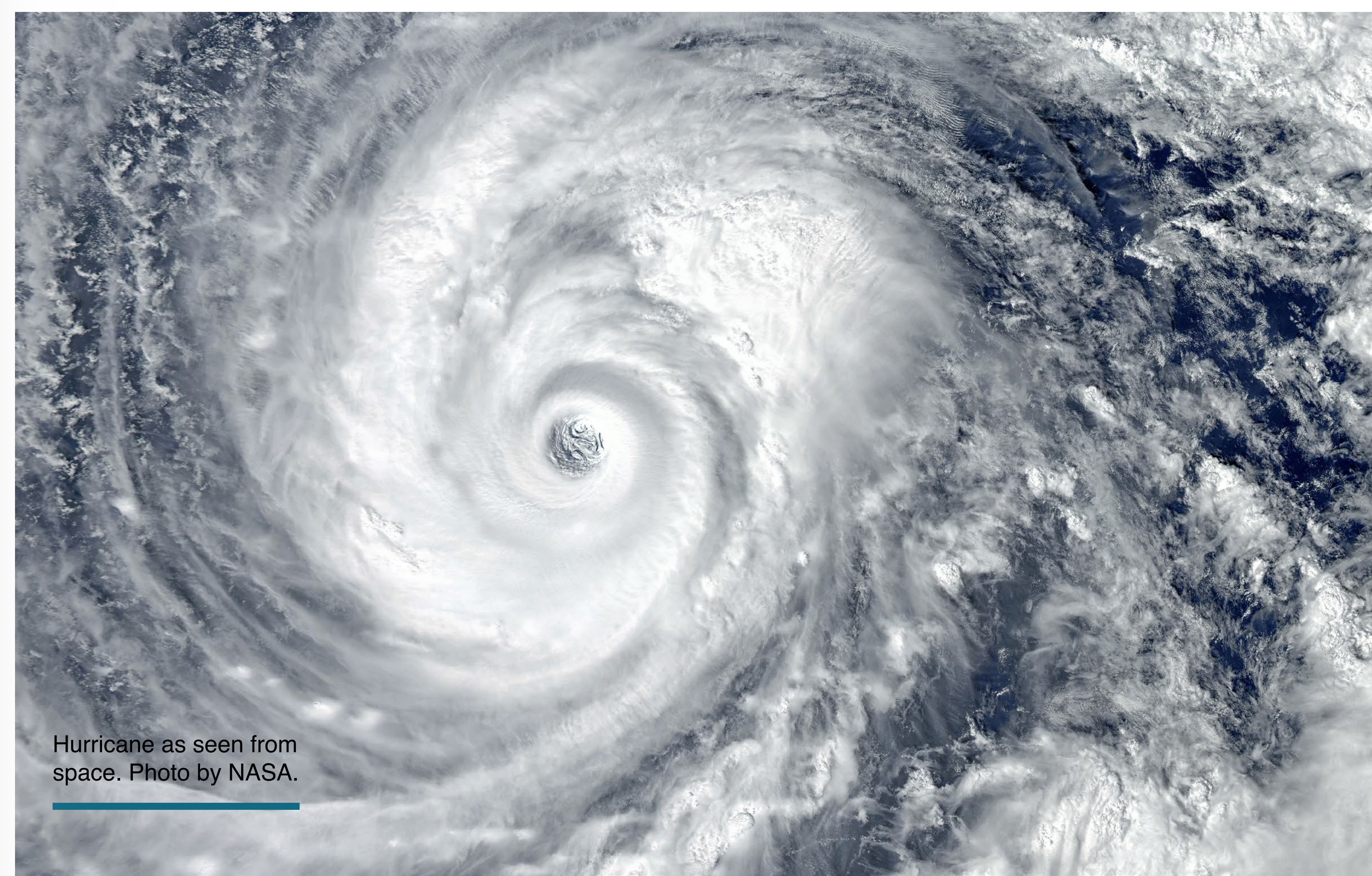
The circulation model uses Reynolds decomposition to split the currents into a time mean-component and a perturbation component. The vertical mixing is defined by the interaction of the horizontal perturbation terms and the vertical perturbation. While the circulation model is able to directly resolve the mean flow, it is unable to directly resolve vertical mixing because it is turbulent and occurs on small scales (both spatially and temporally). To overcome this challenge, circulation models often parameterize vertical mixing via an internal mini-model, which focuses on the generation, dissipation, and vertical propagation of turbulence.

The quantity to estimate turbulence is called the turbulent kinetic energy, or TKE. I modified the existing vertical turbulence scheme by adding two wave components (wave breaking and LT). I included wave breaking by replacing the default surface boundary condition based on the surface wind stress with a new wave breaking-driven boundary condition. This new boundary condition includes the whitecapping only (wave breaking due to steepness) as our idealized study is deep-water everywhere. Langmuir turbulence occurs throughout the upper ocean water column and is added to the TKE equation as a source of turbulence. It is parameterized as the product of the vertical shear of the mean current and the vertical shear of the Stokes drift. Note that the vertical shear refers to the variation of a quantity in the vertical direction where positive means that the quantity decreases with depth. A second component of wave breaking included within the circulation model (not within the vertical mixing parameterization) is as a mean horizontal surface current forced by whitecapping that rapidly decays with depth.

IDEALIZED HURRICANE EXPERIMENTS

I focused on idealized hurricane conditions with prescribed winds and three different constant westward hurricane translation speeds (2.5, 5 and 10 m/s); however, I will focus on the slowest translation speed (2.5 m/s) here. The motivation for such a highly idealized study was to examine and quantify the wave effects on currents (both driven by hurricane winds) without extra complications from bathymetry, background currents, or swell. I set up the model domain as a simple rectangular box with a uniform 5,000 meter bathymetry and no land. All simulations begin with a deep water ocean at rest. The initial conditions are derived from vertical profiles of temperature and salinity from a deep-water location just east of the Caribbean Sea.

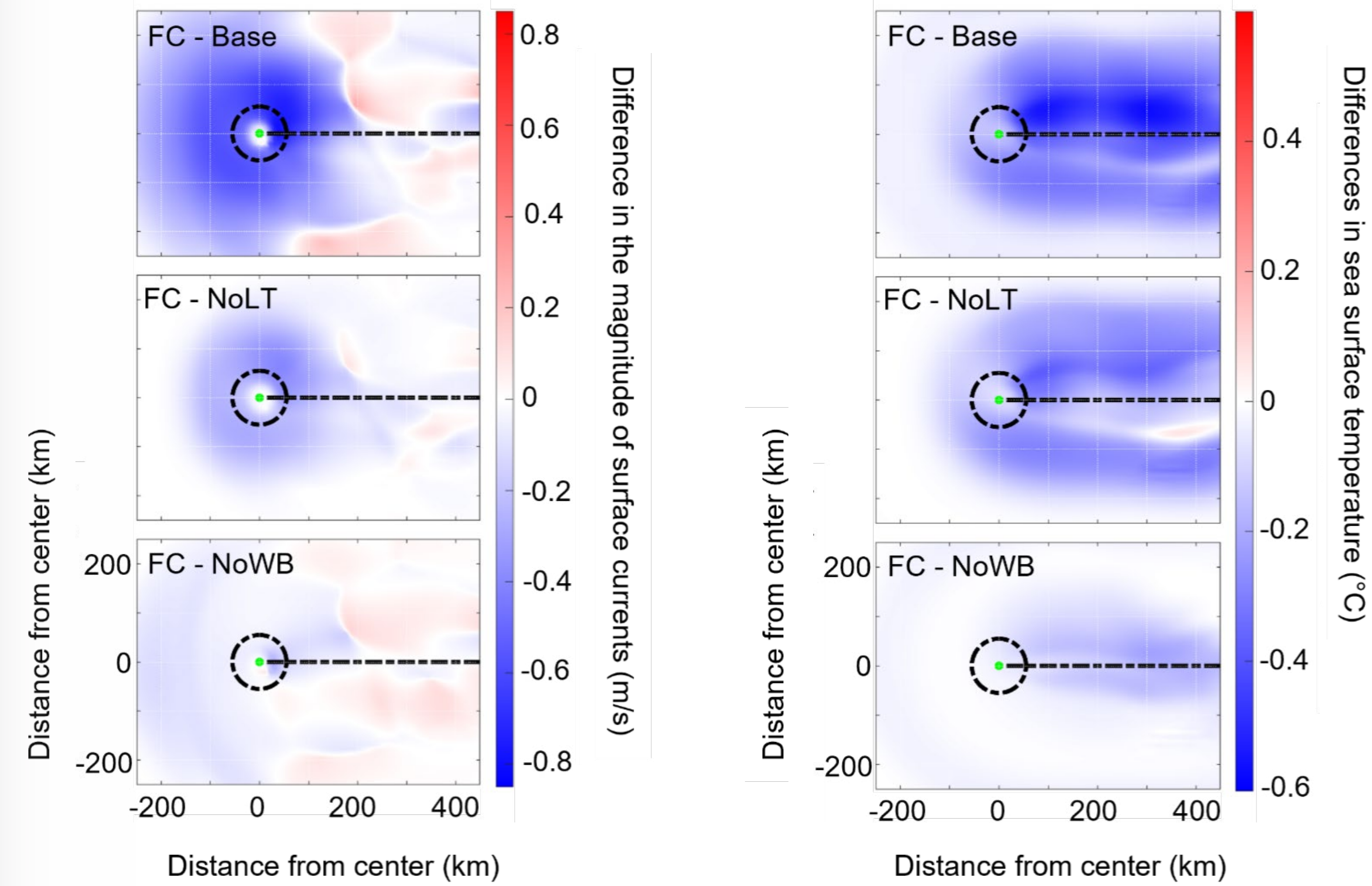
Our study included eight different sensitivity experiments, but I am only focusing on



Hurricane as seen from space. Photo by NASA.

“Langmuir turbulence weakens the surface currents by transporting horizontal momentum vertically down the water column.”

- Colin Hughes, Dalhousie University

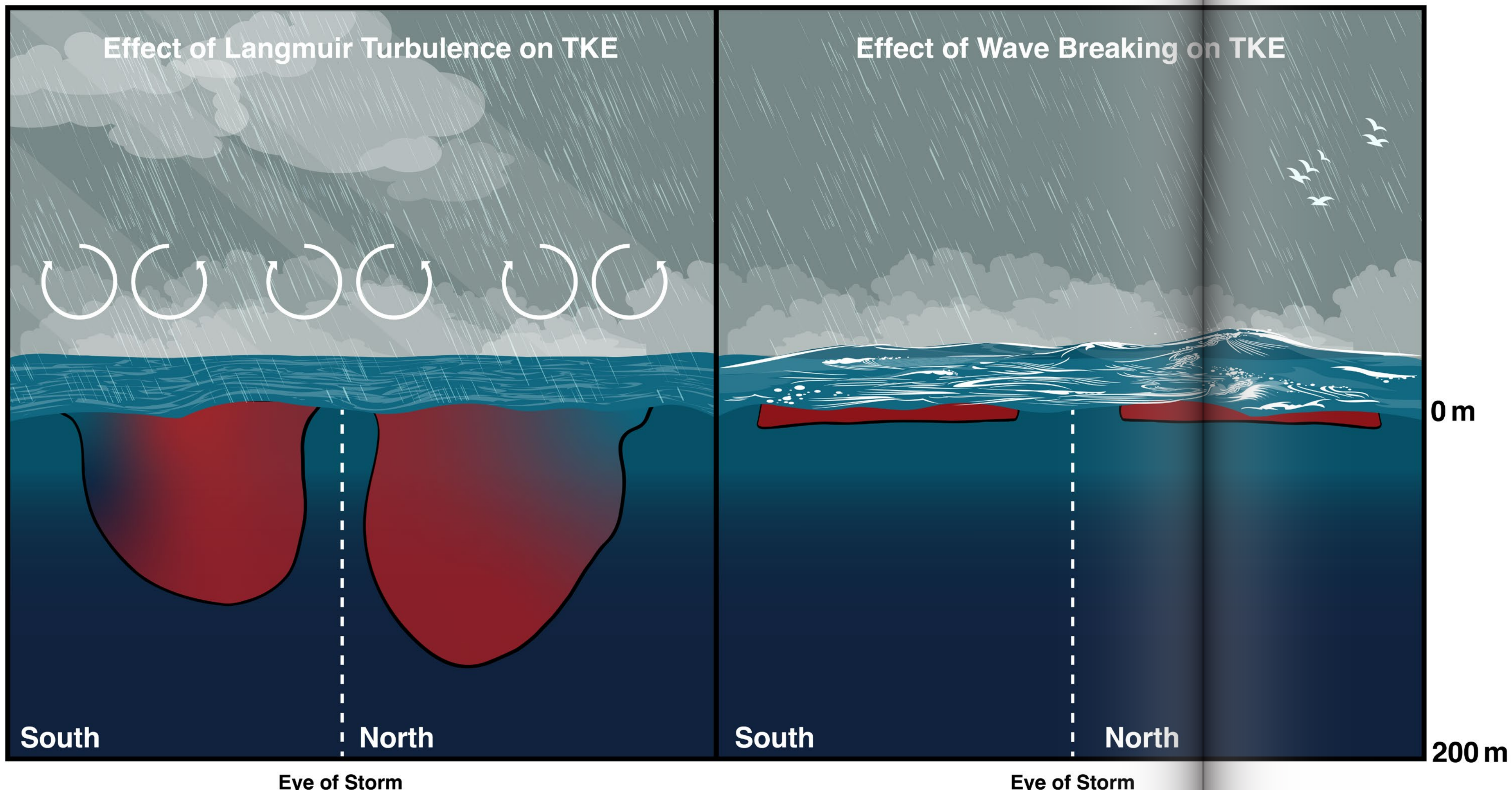


Left: Spatial distribution of the differences in the magnitude of the surface currents (m/s) and, **Right:** Spatial distribution of the differences in the sea surface temperature (SST) (°C) at model time 72 hours for an idealized hurricane moving westward. The dashed black line is the storm track, the dashed black circle is the radius of maximum wind (55 km) and the green dot is the storm center.

five here: a circulation only experiment (Base), a fully coupled experiment (FC), and three experiments that disable one of the components of parameterized turbulence (an experiment without LT (NoLT), an experiment without the wave breaking surface flux of TKE (NoWB TKE), and an experiment without either wave breaking term (NoWB). All of the wave effects (conservative wave effects, wave breaking, LT, and current effects on waves) are included in FC, while none are included in Base. We examined the surface spatial distributions and vertical transects (along and perpendicular to the storm tracks) of the horizontal currents, TKE, temperature, and vertical velocity. Here, I limit the focus to the SST and horizontal currents at the surface and vertical transects of TKE.

LANGMUIR TURBULENCE IS THE DOMINANT CONTRIBUTOR

The largest differences in SST, horizontal currents, and TKE are seen between the FC and Base experiments. Therefore, all three wave effects alter the SST and surface currents. Of the individual wave effects, LT reduced the surface currents the most. LT weakens the surface currents by transporting horizontal momentum vertically down the water column. The surface flux of turbulence also transports momentum



Vertical transects of the turbulence (turbulent kinetic energy or TKE) differences in the north-south directions of a hurricane moving westward with a constant speed of 2.5 m/s. Differences: FC – NoLT (**Left**) and FC – NoWB TKE (**Right**).

down the water column and weakens the surface currents. However, unlike LT, vertical turbulent mixing, generated by wave breaking, is limited to the upper several meters. The wave breaking-induced surface acceleration tends to increase the surface currents. These wave-induced current enhancements are relatively small and tend to occur where the surface currents are weak to begin with. This suggests that waves slightly increase the horizontal advection of surface flow.

The vertical transects of TKE highlight the contributions of waves to the turbulent vertical mixing. The magnitude of turbulence generated by breaking waves is very large (~0.17 m^2/s^2) , but it dissipates near the surface. Langmuir turbulence produces TKE that is an order of magnitude smaller, but that occurs throughout the upper ocean.

Both 1D (vertical mixing) and 3D mixing processes reduce SST and change the upper ocean thermal structure during hurricanes. Vertical shear of the horizontal currents drives turbulent mixing which brings warm surface water down the water column and cooler water up. Furthermore, hurricanes produce a divergence of surface currents and upwelling under the storm center which brings yet more cooler water to the surface. The largest SST differences relative to FC occur in the Base experiment, demonstrating (consistent with the surface currents) that all of the considered wave effects contributed to the SST changes.

CONCLUSIONS AND IMPLICATIONS/ FUTURE DIRECTIONS

In our idealized setup, the LT contributions exceed those of wave breaking and the conservative Stokes drift effects. Both LT and wave breaking increase the downward transport of heat and momentum and the conservative wave effects enhance 3D mixing. The primary takeaway is that waves should be included in hurricane models, and more generally, in ocean circulation models (including for climate studies). Waves increase the vertical mixing and, in doing so, reduce the SST; a cooler SST reduces the latent heat flux which drives hurricane formation, increased wind speed, and maintenance. Therefore, hurricane models which fail to include wave effects can produce inaccurate forecasts.

Accounting for waves in hurricane forecasts should thus result in better hurricane advisories and actions to mitigate the risks posed to lives and property. Models used in forecasts tend to have lower computational limits than those involved in research. However, parametrizing wave contributions can strike a balance between accuracy and computational limits. Simpler options for parameterizing waves exist (i.e., without a wave model coupled to a circulation model), though they will be less accurate. Our future research will investigate wave-current interactions during Hurricane Arthur, which hit Nova Scotia in July 2014. ▶

This research was funded by the Marine Environmental Observation, Prediction and Response Network (MEOPAR), the Northern Regional Association of Coastal Ocean Observing Systems (NERACOOS), the Ocean Frontier Institute (OFI), the Natural Sciences and Engineering Research Council (NSERC), the Canadian Surface Water and Ocean Topography (SWOT) program, the Department of Fisheries and Oceans (DFO), Canada's Aquatic Climate Change Adaptation Services Program (ACCASP), and the Dalhousie University Faculty of Graduate Studies (FGS).

Colin Hughes, Physical Oceanography

Originally from the Philly suburbs, Colin was fascinated by the oceans at an early age. He was particularly captivated by cephalopods, especially his favorite: giant squid. Growing up, he grew more interested in the physical elements of the ocean, especially tsunamis, whirlpools, and rogue waves. Colin's PhD research at Dalhousie University with Dr. William Perrie & Dr. Jinyu Sheng builds upon his master's focus on wave-current interactions during hurricanes. He is excited to switch from modeling idealized storms to a real hurricane. In his free time, Colin enjoys both watching and playing team sports.

FINDING THE NEEDLE IN A HAYSTACK

How to tag, track, and recover data from twenty fish in a pen of 20,000 (or more!)

By Jennie Korus

My alarm goes off at 5am and I jump out of bed. I'm not usually a morning person, but this is an exciting day as I set off to complete my fieldwork. Fieldwork is a big component of many research projects and a critical step in the data collection process. After weeks of planning, I set out along the South Shore of Nova Scotia to an Atlantic Salmon (*Salmo salar*) aquaculture farm in Liverpool.

The goal for the day? Tag twenty fish with two types of data loggers, an acoustic data storage tag from Innovasea and a bio-logger from Star-Oddi. Together, these tags will help collect data on four different parameters: heart rate, acceleration, temperature, and depth. Each tag has been specifically programmed so that its battery and memory capacity will last the entire eight-month duration of the study – a difficult feat for a tag that's about the size of your pinky!

THE SEASIDE OPERATING ROOM

We arrive at the docks and unload the gear onto the boat before steaming about fifteen minutes to the aquaculture site. The site has fourteen pens, aligned in a grid formation. Once the boat is tied off at the test pen, we undo some of the netting to access the fish and set up our mobile operating room. Fish surgery is not too dissimilar to any other surgical procedure - you require a scalpel, needles with suture, a surgery table, a method to provide continuous oxygen to the patient, and a way to sterilize all tools, including the tags. To prepare the anesthetic, a powder is dissolved in water at a very specific concentration – just enough to make the fish lose consciousness but not enough to cause adverse effects. One at a time, each fish is placed in an anesthetic bath for five to seven minutes, and when it no longer reacts to slight pinches on

The sun rises at Liverpool Farm as the research team approaches the study cage and begins prepping fish for surgery. Photo by Jennie Korus.

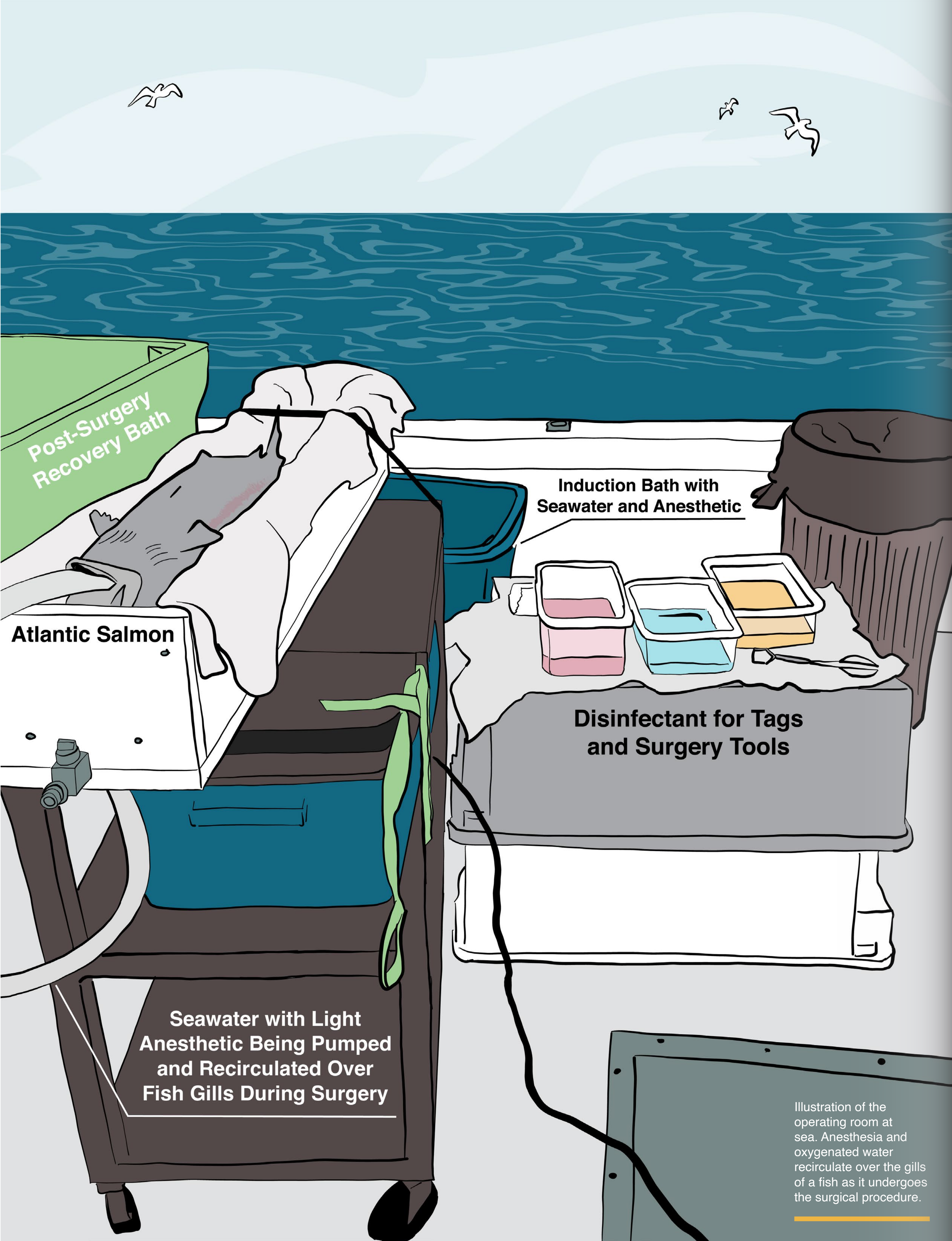


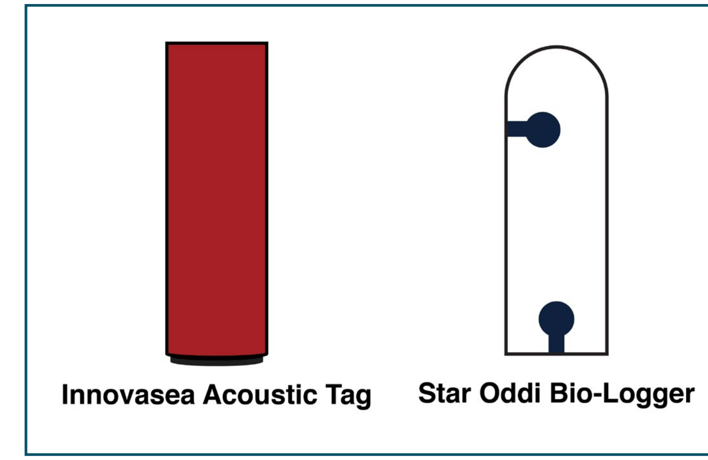
Illustration of the operating room at sea. Anesthesia and oxygenated water recirculate over the gills of a fish as it undergoes the surgical procedure.

the dorsal fin, it is brought to a scale where it is weighed and measured.

The fish is then transferred to the surgery table where a small tube is placed in its mouth. This tube circulates oxygenated water containing a lighter dose of anesthetic through the fish's gills. A 5-cm incision is made just caudal (towards the tail) of the pectoral fins. The Starr-Oddi tag is implanted first; it gets pushed in towards the head, with the two tiny electrodes facing down, and must be sutured in place. This tag must remain in the correct orientation and as close to the heart as possible to record high quality heart beats. Next, the Innovasea tag is pushed in toward the tail and remains free moving within the body cavity. This tag does not need a precise location as it only records acceleration and depth. With both tags in place, the incision is closed, and the fish is placed in a recovery bath. To significantly aid each salmon's recovery from surgery, a hose providing clean, oxygenated water is left running in the recovery tank. Each fish is different and recovery time varies, but the goal is to return them to their ocean net pen in an as-normal-as-possible state, increasing their chances for survival.

STORMY SEAS AHEAD

The day started out as a beautiful, calm, sunny day and as we move through each fish, we improve our efficiency every time, and at around 2 pm we feel like we're making great progress as we've completed about fifteen surgeries. But that's the thing about fieldwork – it almost never goes according to plan! The wind begins to pick up, increasing the wave action. Now, not only is each surgery much more difficult, but unbeknownst to us, as the larger waves slosh against the walls of the recovery tank, significant amounts of water spill out and onto the boat deck. Even worse, this water was leaking into the boat



engine! Of course, this only became apparent about an hour later, when we tried to move the boat to calmer seas, and it refused to start. The engine was flooded! Cue mild panic as we determine just how dire our situation has become.

While the veterinarian and I attempted to finish tagging as many fish as possible, the boat captain bailed pail after pail of water from the engine. After about an hour of bailing and some minor engine troubleshooting, the boat is finally running again but the recovery tank is no longer an option. It had to be emptied before our last two tagged fish were fully recovered. Still, we managed to tag seventeen fish in total before making it safely back to shore. Not bad for a day out on some rough seas!

REAL TIME DATA COLLECTION

Our tagged fish will now swim around, collecting data for the next eight months, until they are harvested sometime in August. That's when the next challenge begins. How do you retrieve tags from seventeen fish swimming around with 20,000 others? Well, each of our fish was tagged with an external floy tag, a small, fluorescent, T-bar tag (like those that you find on new clothes), to aid in identification. Our tagged fish represent less than 0.1 percent of the total so picking them out will not be an easy task. But the effort is

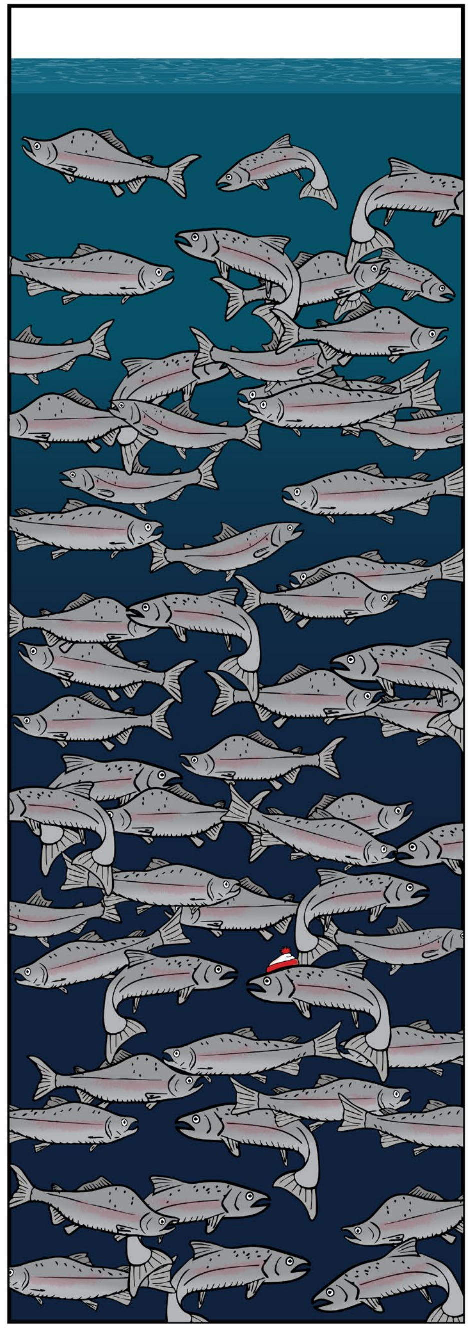
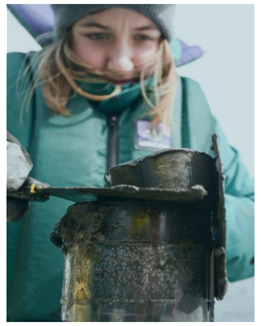


Illustration of farmed salmon in a "Where's Waldo" inspired cartoon which represents the difficulty in retrieving tagged fish as they go through the harvesting procedure.

worth it. It is critical to retrieve as many tags as possible; the majority of data is stored internally and each tag that goes unrecovered represents a significant amount of data lost. Not to mention there is always a chance that our tagged fish do not survive to the harvesting date. Surgery is a major stressor and while good recovery time and smooth surgeries enable stronger survival rates, there's no guarantee. Fortunately, the Innovasea tag acoustically transmits acceleration and depth in real-time, a significant benefit, which means I have been able to check in and see how the fish are behaving. While a majority seem to be alive and well, unfortunately, the two fish who were unable to recover properly have died. Given the circumstances - that's not too bad!

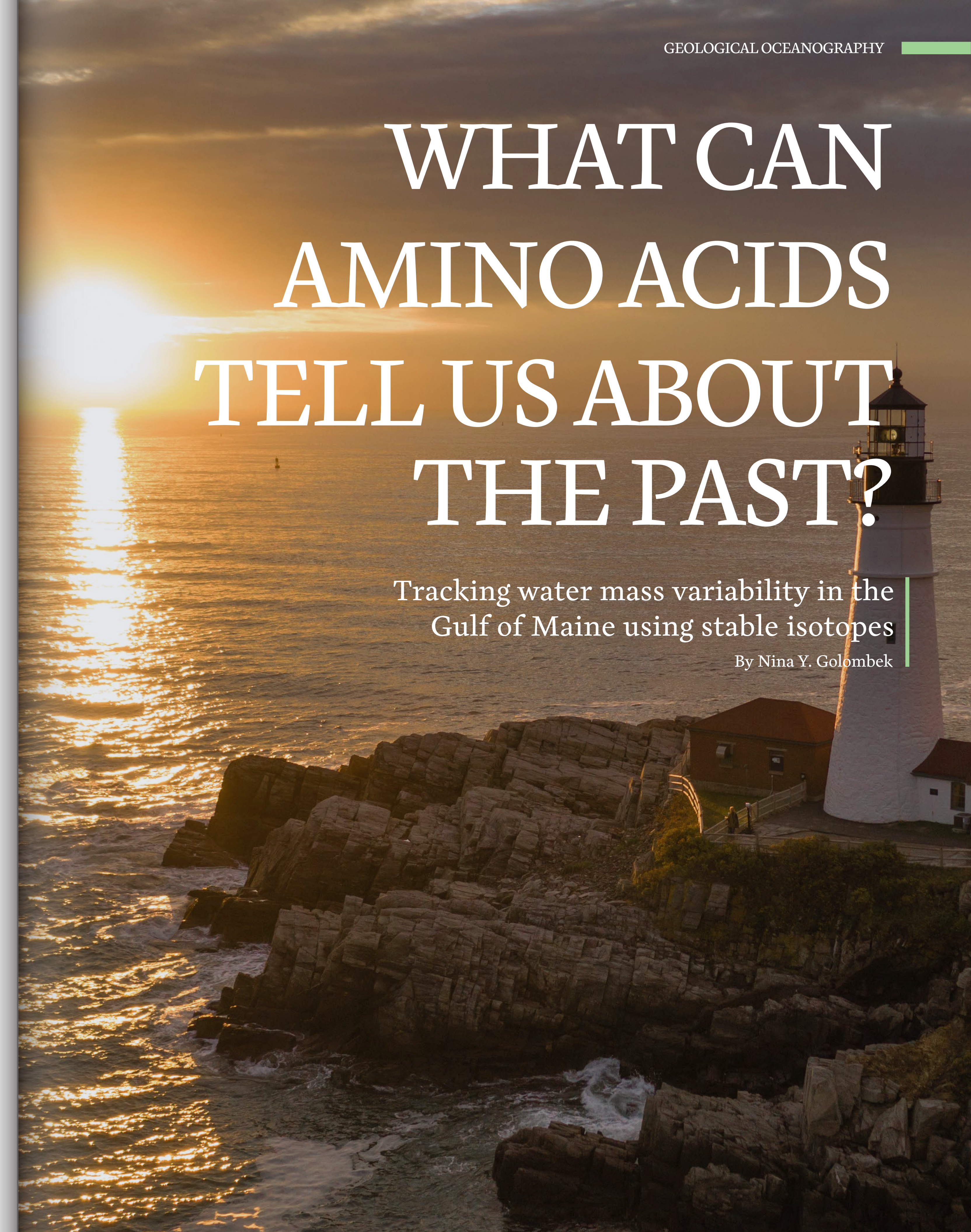
So, what is all this data used for? By collecting these parameters over a eight-month period, we hope to characterize the stress response that fish undergo when exposed to various stressors. Stressors may be environmental or operational in nature but by collecting environmental data, such as temperature and oxygen, as well as a daily log of farm activities and feeding regimes, we can observe how fish respond to various events. This will help us derive important insights into the daily lives of farmed fish which we can pass onto farmers, allowing them to provide better care to their fish stocks. Although data is not currently available directly to the farmer in real-time, as technology advances, tagging of farmed fish may become common practice. This could have a significant impact on how farmers make operational decisions when it comes to the health and wellbeing of their fish. Not only that, but a happy, unstressed fish grows faster and produces a better product. Shorter grow-out cycles are more cost-effective and better for the surrounding environment. This data is vital – even if it means difficult fish surgeries, unexpected boat complications and, of course, combing through 20,000 fish to find our needles in the haystack!

This research was funded by Innovasea in partnership with Cooke Aquaculture.



Jennie Korus, Biological Oceanography

Originally from Toronto, Jennie always knew she wanted to study the ocean. She moved to the East Coast and obtained an honors degree in Marine Biology and Statistics from Dalhousie University and an advanced diploma in Ocean Technology from NSCC. Jennie works full time as an aquaculture scientist at Innovasea as part of the Aquaculture Intelligence team. Her part-time research in Oceanography at Dalhousie is focused on fish stress and environmental monitoring on aquaculture farms. In her spare time, Jennie is either playing fetch with her mischievous dachshund Howie or competing at Ultimate Frisbee tournaments across North America.



WHAT CAN AMINO ACIDS TELL US ABOUT THE PAST?

Tracking water mass variability in the Gulf of Maine using stable isotopes

By Nina Y. Golombek

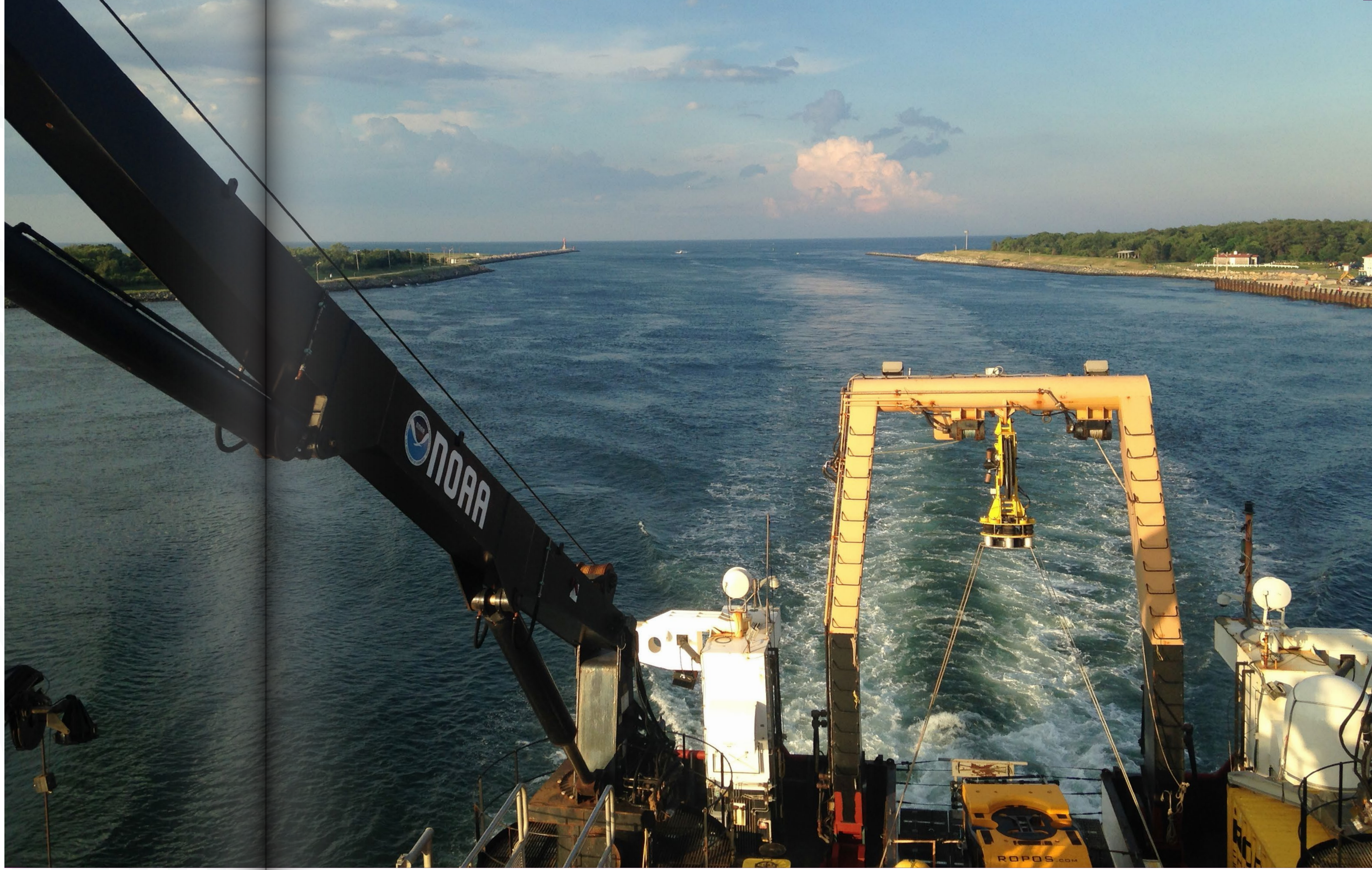
THE PAST IS THE KEY TO THE FUTURE – PALEOCEANOGRAPHY IN ACTION

Since the beginning of the industrial revolution, the surface ocean has been warming at an alarming rate. The ocean ebbs and flows in natural cycles, making it difficult to tease out which fluctuations are natural, and which are caused by human activities. On the bright side, the climate crisis has sparked a new generation of ocean observation, recording changes in the characteristics and movement of water masses. But monitoring stations are limited to only the past few decades and a few 'popular' deployment regions and therefore, cannot tell us the whole story. If only researchers could hop into a time machine to study pre-industrial ocean conditions.

Well, it turns out we can! Paleoceanography studies the oceans as they were in the past. Using sediment records and long-lived organisms, we can generate records on geological time scales (decades to millions of years). These geological records are the missing puzzle pieces that allow scientists to distinguish natural, periodic changes from those induced by human activities. Studying the past is the key to understanding the present and future; results from palaeoceanographic research can be used to improve model predictions under potential future climate change scenarios.

Corals, mussels, and organic material from dead organisms in sediments hold key information we need to detect long-term changes in ocean properties and nutrient sources. Paleoceanographers call these 'paleo-archives'. Each archive has a characteristic 'chemical fingerprint' (i.e., isotopic signature) allowing us to characterize the origins and cycling of elements like nitrogen (N) or carbon (C) in a sample. Isotope analysis of sediment as a whole, called bulk material, is a common tool to identify fine-scale differences between 'chemical fingerprints' that can be correlated with shifts in regional and global parameters over various time scales, like glaciations or climate change. However, these measurements provide multiple challenges when used for paleoceanographic interpretations. A novel technique has been developed to measure isotopes in specific compounds like amino acids (AAs), the building blocks of life. My Ph.D. research tests the use of AA specific isotope analysis on marine sedimentary organic material to investigate ecosystem changes over geological timescales and reconstruct nutrient-plankton dynamics in the climatically-sensitive northwest Atlantic margin.

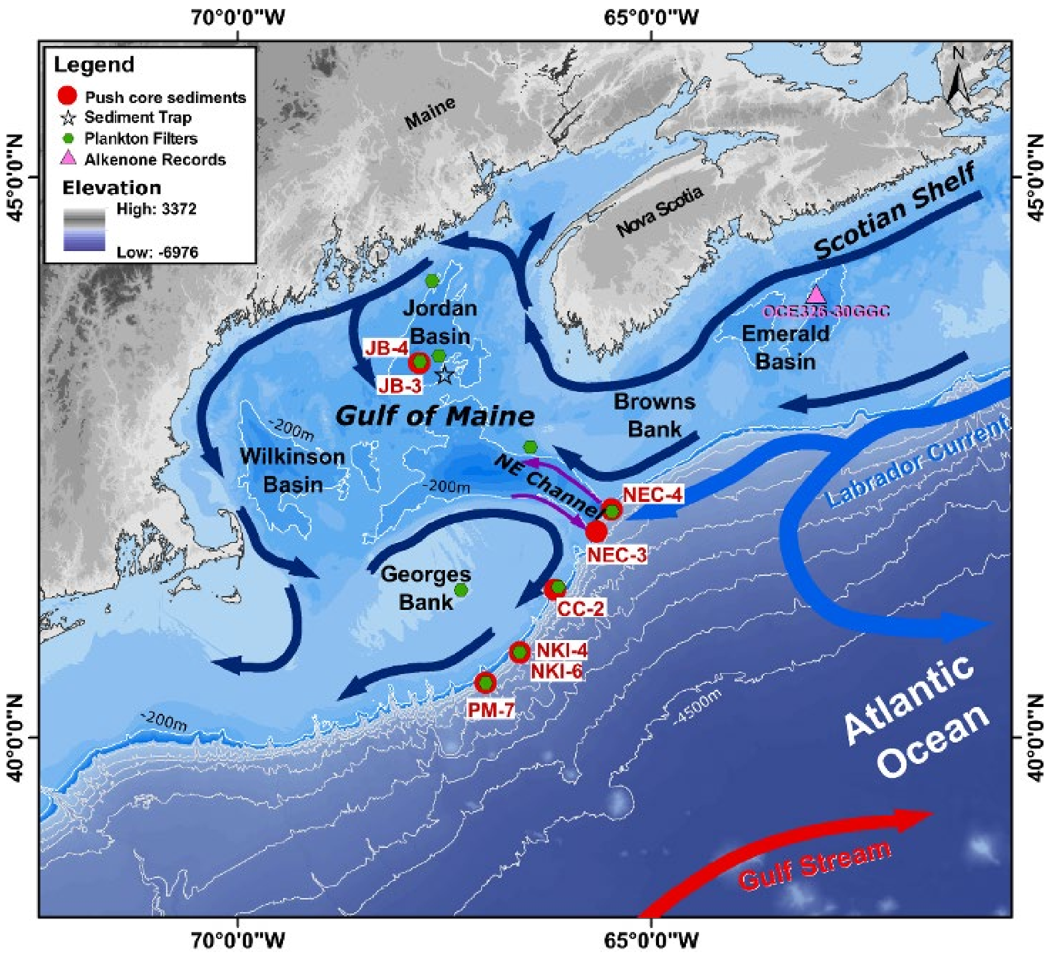
> "The ocean ebbs and flows in natural cycles, making it difficult to tease out which fluctuations are natural, and which are caused by human activities."
> - Nina Y. Golombek, Dalhousie University



ROPOS ROV sitting on the deck of the Henry B. Bigelow research vessel. Photo by Arieanna Balbar.

GULF OF MAINE – A HOTSPOT FOR WARMING AND BIOGEOCHEMICAL CHANGES

The Gulf of Maine is a semi-enclosed continental shelf basin in the northwest Atlantic Ocean located at the junction of the northward-flowing Gulf Stream and the southward-flowing Labrador Current. Interannual variations in the strengths and positions of these current systems determine the relative proportion of subtropical versus subarctic water masses entering the Gulf, thereby influencing hydrography and nutrient distributions. These water masses are major sources of dissolved inorganic nutrients which drive the biological productivity and structure of planktonic ecosystems in the region. The Gulf of Maine is also warming faster than 99% of the rest of the ocean and future temperature



Left: Map of the Gulf of Maine and Scotian Shelf region showing the flow directions of major ocean currents and our sampling locations for different materials (Golombek et al., in prep). **Right:** Schematic overview of sample collection in the Gulf of Maine. Water mass directions and positions are for visualization purposes only and do not depict their natural occurrence.

increases are predicted. Previous decades recorded a high contribution of colder, fresher, and nutrient-poor Arctic source water masses but in the last decade, increased bottom-water temperatures have been, in part, attributed to an increased influx of warmer, nutrient-rich Gulf Stream associated waters.

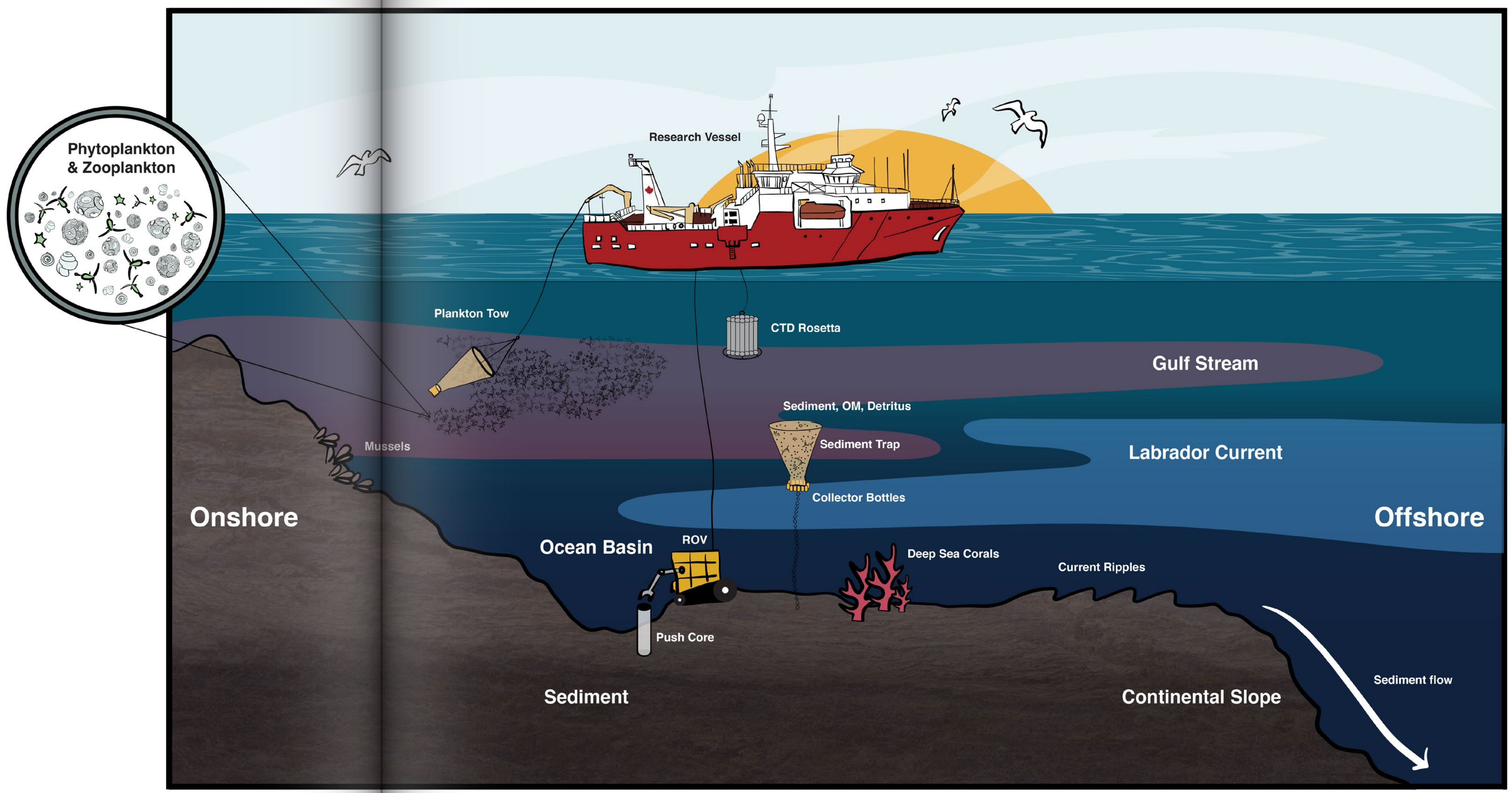
But what led to this change in source water regions? Is this simply a natural fluctuation or triggered by human-induced climate change? To answer this question, I look at long-term sediment core records to understand regional changes in source-water masses over geological timescales. But first, we must gather our chemistry kit and work some magic!

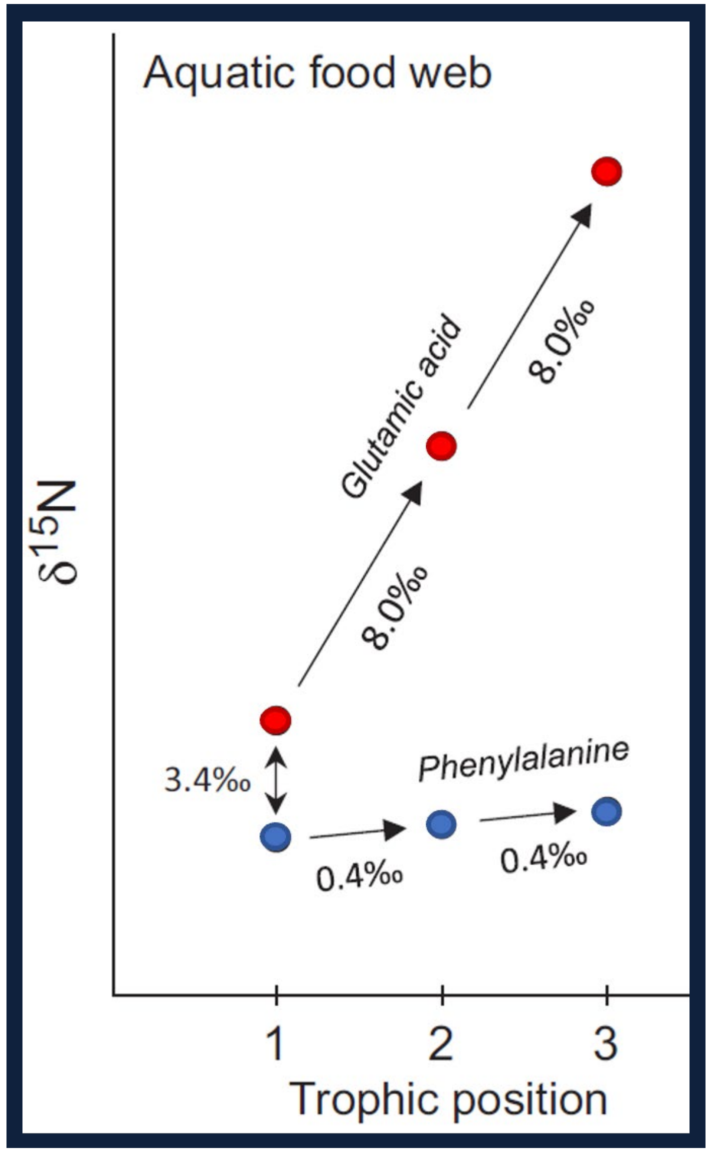
THE CIRCLE OF LIFE – HOW NITROGEN ISOTOPES IN THE OCEAN CAN HELP UNTANGLE THE FOOD WEB OF THE PAST

Nutrients are substances essential to the circle of life that are continuously produced, used, excreted, and re-incorporated – in a global cycle. Plants in your garden need them to grow just as marine organisms need them to survive – from the tiniest plankton to the largest whale. Nitrogen (N) is a key element that regulates marine life and global climate. Its various transformations through the N-cycle lead to enrichment (>0‰) or depletion (<0‰) of N isotopes relative to their measured values in air (which mainly contains N_2, set to 0‰) and, thus, the 'chemical fingerprint' changes depending on specific biological and chemical processes. When analyzed, this information can offer insights on how nitrogen moved through the N-cycle.

Nitrate is the predominant form of N in the ocean and can easily utilized by organisms. Its isotopic signatures vary regionally because of complex interplays between nitrate sources and sinks, leaving different oceanic regions with distinct isotopic fingerprints. In the North Atlantic, Gulf Stream associated waters have lower isotopic values for nitrate, while Labrador Current waters have higher isotopic values – like the fingerprints of two separate people. These distinct isotopic differences, expressed in per mill (‰), can then be used to track water mass origins. Primary producers in the surface ocean, like phytoplankton, take up the isotopic signatures of the water mass in which they grew in. As these organisms die and sink to the sea floor, they are deposited as organic material (OM) in sediments. Et voilà – the isotopic fingerprint of a water mass is now stored in the isotopic signature of OM in marine sediments. Our

SAMPLE COLLECTION IN THE GULF OF MAINE





Isotopic enrichment of nitrogen isotopes in different AA with each step up the food chain. Blue dots represent Source-AA that remain essentially unaltered; red dots represent Trophic-AA that become progressively enriched (heavier). Adapted from Ohkouchi et al. (2017).

analysis can now begin! This will potentially provide a record of past changes in the N-cycle.

But which organisms are reflected in the measured isotope values? And has the signal been altered since deposition? Bulk isotope analysis cannot answer these questions, but that's where amino acids enter the picture! Amino acids make up most organic material. Thus, analyzing their isotopic fingerprint allows us to determine how much of our signal has been altered by microbial activity before and after deposition in our sediments, altering the isotopic signal of our sediment. It also provides a proxy for what the 'original signal' from primary producers looked like.

YOU ARE WHAT YOU EAT – HOW AMINO ACIDS CAN TRACK WATER MASSES

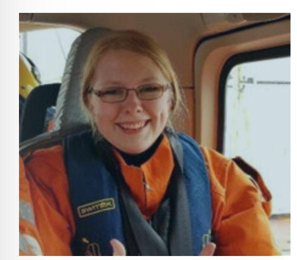
Let's look at our amino acids (AA) in more detail. Imagine a set of AA inside a phytoplankton, which is then eaten by zooplankton, then fish, etc., slowly making their way up the food chain. Some AA keep their original isotopic signature with each step up the food chain, while other AA become isotopically enriched (heavier). These are called Source-AA and Trophic-AA, respectively. We can use the isotopic differences between these groups to estimate which organisms are reflected in our sample and how much our isotopic values were altered by microbial degradation. In other words, we can tell if the isotopic fingerprint we see belongs to the organisms we expect or if it has been altered over time. Moreover, the isotopic fingerprint of our Source-AA can be used as a direct proxy for the isotopic fingerprint of nitrate in the source water mass, as it reflects baseline values of the exported primary production.

So, what have we got so far? We know the isotopic fingerprints of our two source water masses: the Gulf Stream and the Labrador Current. We can infer the isotopic signatures of primary producers in our sediment - therefore, any changes in isotopes over time can be interpreted as changes to the origin of the source water mass at that location. And because water mass changes don't happen overnight, and these changes last for extended periods of time, we can look at fluctuations over thousands of years to understand if recent observed trends are of natural or anthropogenic origin.

LET'S DIG IN! – THE JOYS OF PLAYING WITH DIRT!

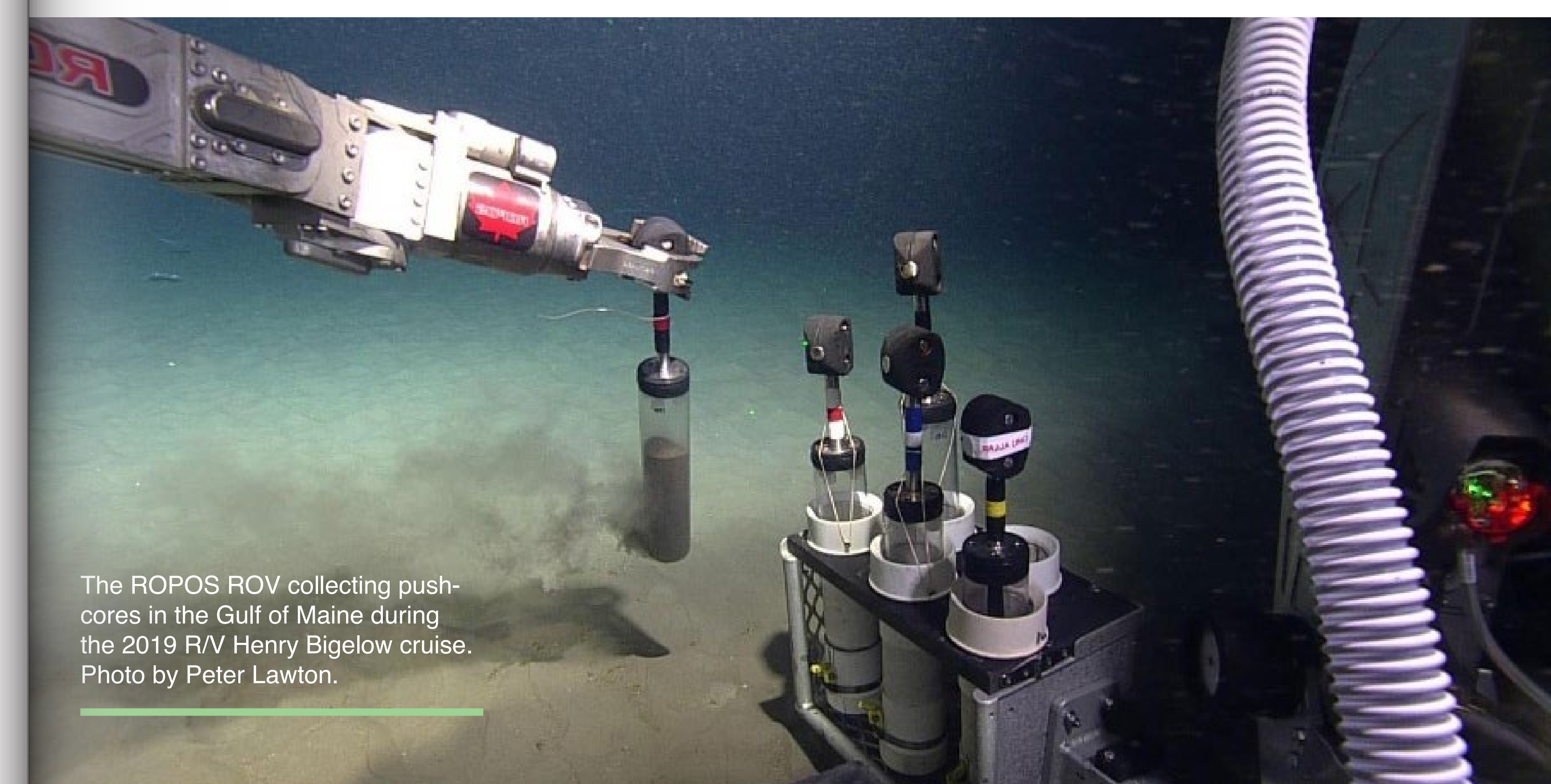
So where do we go to test this approach? We collected sediment cores, sediment traps and plankton filters across the Gulf of Maine and Scotian Shelf region. After chemical preparation, we measured the N isotopes for twelve AA in each sample and used statistical analysis to evaluate our findings. Preliminary results show that between locations, variations in amino acid-specific nitrogen isotopes reflect the contribution of different water masses across the region. Further, even in samples that show enhanced microbial degradation, the isotopic fingerprint of the Source-AA aligns with what is expected to be found in primary producers (i.e., phytoplankton). Therefore, this novel technique can be used as a proxy to reconstruct nutrient-productivity dynamics in the climatically-sensitive northwest Atlantic margin! Our next steps will be to evaluate the preservation of isotopic signals from primary producers throughout the water column by looking at plankton filters and sediment traps. Ultimately, we will use this data to analyse sediment cores that can resolve water mass changes over the last 4000 years, increasing our ability to separate anthropogenic changes from natural fluctuations in this rapidly changing region. ▶

This research was funded by the Nova Scotia Graduate Scholarship (NSGS), Earth Sciences Doctoral Award and NSERC Strategic Partnership for Projects grant to O. Sherwood and M. Kienast.

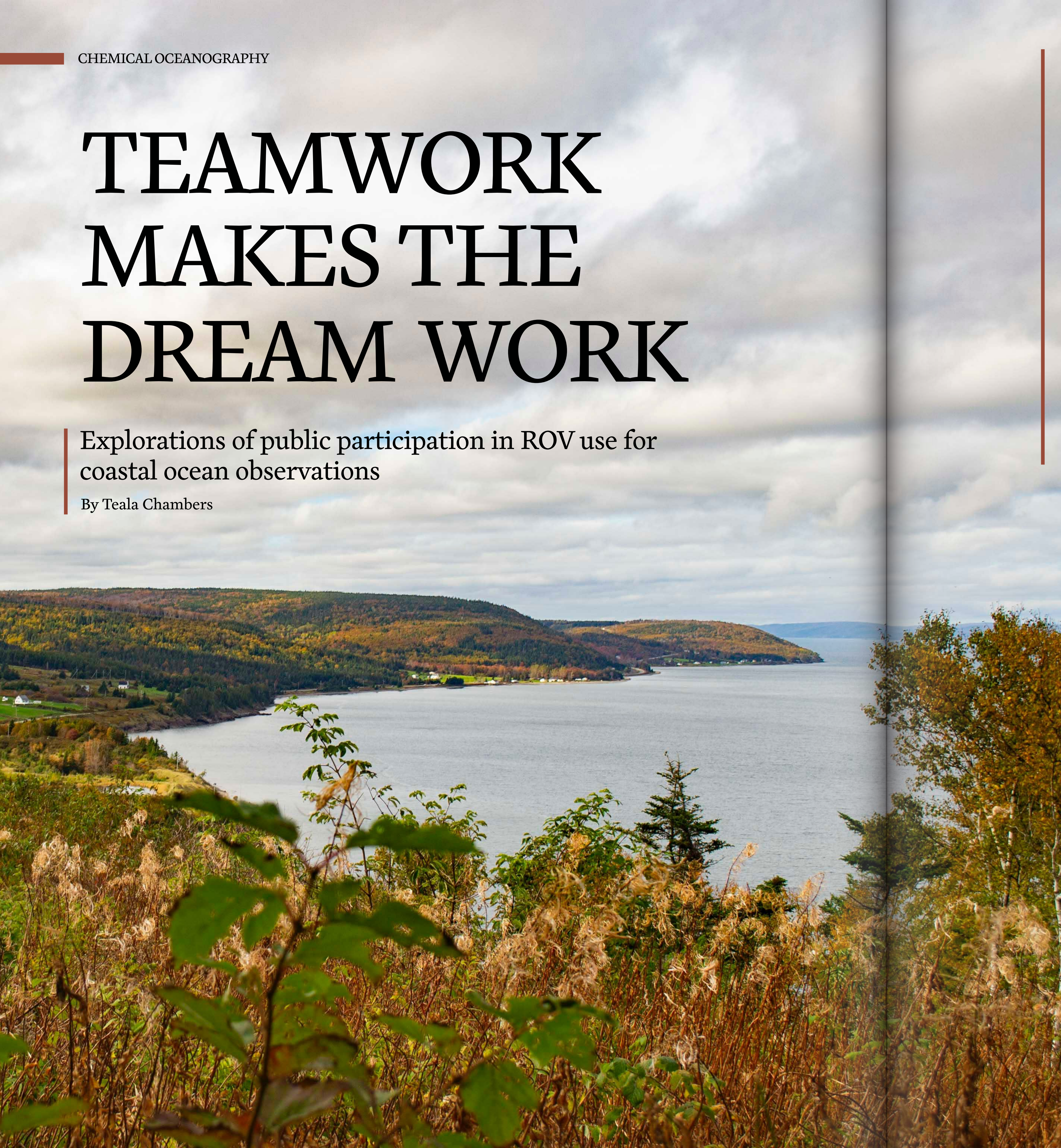


Nina Y. Golombek, Geological Oceanography

Nina grew up in Berlin without an ocean in sight. She was, therefore, expected to study terrestrial Geosciences. After many years and field trips across Europe, she finally found her destiny in the oceans and isotopes, despite incredibly annoying measurements and countless machine breakdowns at University College London and the German Research Centre for Geosciences in Potsdam. Now she is pursuing her Ph.D. in Earth Sciences working in biogeochemistry and paleoceanography with Professors Owen Sherwood and Markus Kienast. When not in the lab, she indulges in traditional archery, latin and ballroom dancing, baking, and volunteering.



The ROPOS ROV collecting push-cores in the Gulf of Maine during the 2019 R/V Henry Bigelow cruise. Photo by Peter Lawton.



TEAMWORK MAKES THE DREAM WORK

Explorations of public participation in ROV use for coastal ocean observations

By Teala Chambers

Teamwork; it's important in everything from sports to science. While science may not always require athletic ability, the importance of working towards a common goal is consistent.

BlueRobotics' BlueROV2 ready to be deployed.

This is especially true of community engagement in science, where scientists work with communities to collaboratively address local problems or needs. Technological advancements have opened up new opportunities for this partnership; when communities can play a role in monitoring, they can inform the planning, operations, and regulation of their underwater backyard.

EQUIPMENT

Affordability has long been the major hurdle in adopting emerging technologies, but decreasing costs and increased use of open-source platforms with simple user-interfaces have made technology more accessible for ocean observations. For example, the first tethered remotely operated vehicles (ROVs) were created almost eighty years ago, but with technological advances they are now smaller, cheaper, and easier to use. The CERC.OCEAN Lab's researchers (myself included) are investigating the potential of BlueRobotics BlueROV2 to address coastal community interests. With a price tag between $3000 and $5000, this ROV is comparatively inexpensive and works with a video game controller and any old laptop. Moreover, all the information needed to run it is open-source, making it easier to troubleshoot and modify quickly. No longer does one need to be an ROV specialist to use this tech!

OUR PLAYING FIELD

The Bras d'Or Lake in Cape Breton offered a distinctive opportunity to test the ROV in a dynamic, coastal ecosystem in close proximity to a local community, supporting our goals for community engagement. We connected with local leaders in ecological research from the Unama'ki Institute of Natural Resources (UINR), the Collaborative Environmental Planning Initiative (CEPI), and researchers from Cape Breton University (CBU). Together, we identified the barachois ponds of the Bras d'Or Lake as our starting point.

Barachois ponds are located along the shorelines of lakes, with barrier beaches separating the ponds from the larger body of water. With over 400 ponds scattered around the shore, they make up about 12% of the Bras d'Or coastline. An important part of this ecosystem, barachois ponds are valued as natural harbours that offer protection against storms and shoreline erosion. As small bodies of water, they provide essential habitat for many plants and animals and are thought to be areas of high biodiversity. Each pond has distinct hydrological conditions that affect the type of ecosystem it can support. For the local community, they serve as important places of recreation, swimming, skating, and fishing.

Unfortunately, this ecosystem is at high risk of being altered or destroyed. Due to their small size, barachois ponds are especially threatened by anthropogenic disturbances, with eutrophication and rising sea levels among their most pressing threats. Land development poses another problem as physically altering these ponds by widening them to create space for a marina or infilling them to make roads is a common practice. Unlike most of Nova Scotia's wetlands which are covered by the Nova Scotia Wetlands Conservation Policy, most barachois ponds fall below the current size-dependent threshold for wetland protection. Therefore, no government approval is needed for their alteration. Establishing a baseline range for the physical and chemical properties of these ponds is essential to better understand the ecological role these ponds play in the greater Bras d'Or ecosystem and could justify future protection from development.

TEAM PRACTICE

With the hope that we could contribute to this conservation process, it was time to go to the field and spend some time practicing with the ROV. We aimed to assess its ability to accurately reflect pond temperature and salinity by comparing our observations to established CTD casts. Community involvement and participation was crucial to our research and technical testing. We planned to engage locals so that they could advise the development of specific technology for our shared research interests. Community members helped us select Irish Vale Pond because of its ease of access and manageable size. We ran two field tests, one month apart, with researchers from the UINR, CEPI, CBU, as well as other community members.

Working alongside community members was an incredibly memorable experience. We wanted to ensure that they witnessed the ROV in use and tested it themselves; they saw data in real time, while exploring different aspects of the pond and the ROV. The presence of community members with extensive knowledge of the pond, including its species composition and changing visual conditions, made it clear how the community may guide future research. For example, ROV thrusters are negatively affected by jellyfish. But community members know when they are seasonally present in the pond, so such problems can be avoided.

REVISING OUR GAME PLAN

After our technical test and demonstration, we needed to revise and adapt our technology to improve the quality of our

Left: Irish Vale Barachois Pond. Photo by Teala Chambers; **Middle:** Picture taken on a field test day by the ROV; **Right:** PhD student Allison Chua shelters laptop from the rain at the study site (or at Irish Vale). Photo by Teala Chambers.

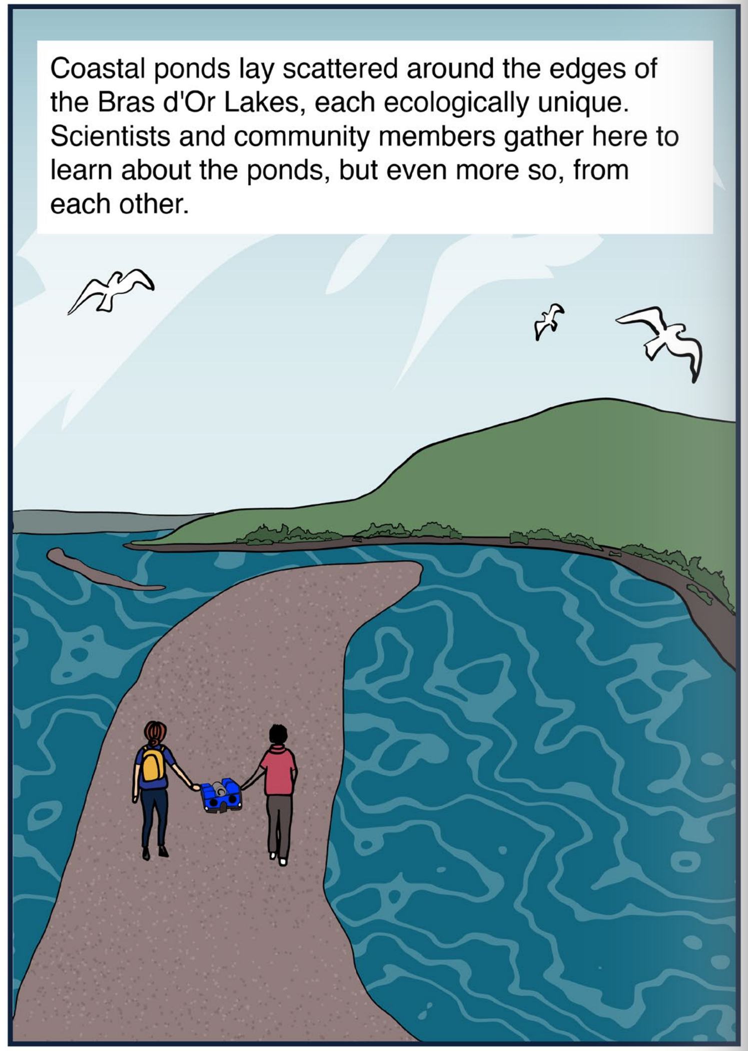
results. Temperature and salinity data from the first field test day contained erroneous values, with some measurements even missing. We hypothesized that this was due to sensor misplacement. Understanding the implications of sensor placement will be key to using the ROV for research purposes that may require high accuracy—for example, the resolution of a fine gradient to observe a thermocline.

We approached our second field test with a new sensor configuration. Gathering some preliminary data on the pond, our ROV measured the depth to be 3.7 m, a reading corroborated by CTD measurements. Interestingly this was 53% deeper than what was reported in a 2014 bathymetric study using acoustic data. We also observed an average temperature of 18.9 degrees Celsius and average salinity of 20.9 parts per thousand (similar to our hypotheses!).

To gauge the opinions of community members involved in the field test, we conducted a survey of those who participated. We wanted to know if they thought the ROV could be helpful for their interests and how they thought we could adapt or change it to better suit their needs. By working together and evaluating the ROV as a team, we hope to make it as useful as possible. The results from the survey were encouraging. The ROV was viewed as useful technology and the community had a lot of exciting ideas that we hadn't considered, including testing ice thickness as an indicator for climate change, using chemical measurements to support habitat mapping, and educating the public through videos taken from the perspective of marine wildlife.

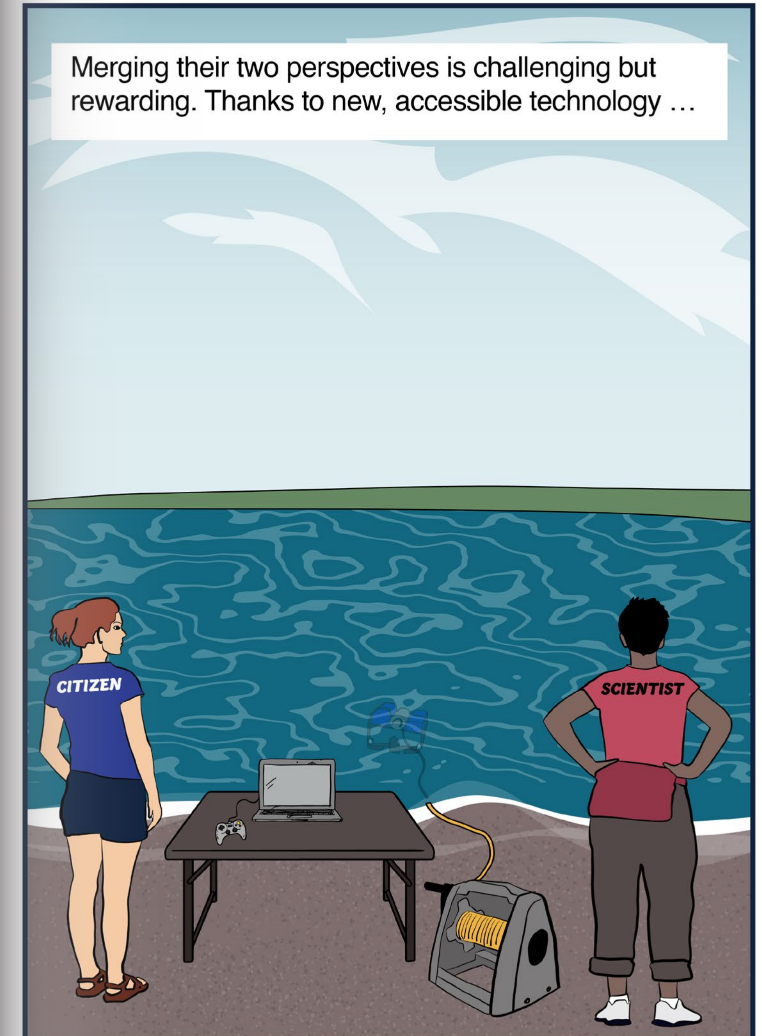
THE FINAL SCORE: PLAYING AS TEAMMATES, NOT OPPONENTS

One of the challenges of community engagement in science is combining different



priorities and methods of knowing. The rigid, quantitative nature of scientific research can be at odds with the more qualitative or subjective priorities of a community. Partnering different perspectives is a major challenge—especially when they seem to be in direct opposition. But differences of opinion can lead to further investigation and diverse perspectives can enhance understanding of a problem and the quality of the solution.

Using the ROV for storytelling and to connect people with the barachois ponds were identified by community participants as one of its major uses. As scientists, storytelling isn't always the first thing that comes to mind when considering a developing technology, but maybe it should be. The barachois ponds provide interesting conditions for

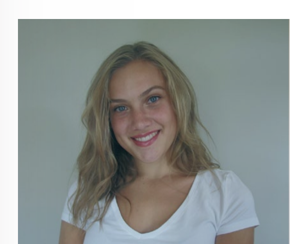


scientific exploration but they are at risk of disappearing before this work can be conducted. Using the ROV to do a different sort of ocean observation on top of what was first envisioned can stimulate public interest to support initiatives for barachois pond conservation, creating a synergy between science and the community. ▸

Covid Statement

This research was completed in the midst of the ongoing COVID-19 pandemic. We were lucky to have relatively relaxed restrictions in Nova Scotia and operating outdoors from the shore allowed us to practice social distancing while wearing masks. The pandemic requires creative solutions if we are to engage communities in science, but this may enable greater outreach, participation, and accessibility in the future.

This work was supported by Mitacs through the Mitacs Research Training Award during Teala's Honours.



Teala Chambers, Chemical Oceanography

Teala grew up in a town nestled between the Niagara escarpment and Lake Ontario, inspiring her interest in natural sciences from a young age. She went on to pursue a BSc in Oceanography at Dalhousie University. She is excited to start her master's studies with Dr. Douglas Wallace, where she will be able to further explore her passions in ocean sciences. She is particularly interested in science communication, marine chemistry, and technology. Outside of school, she enjoys spending time in nature and knitting.

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