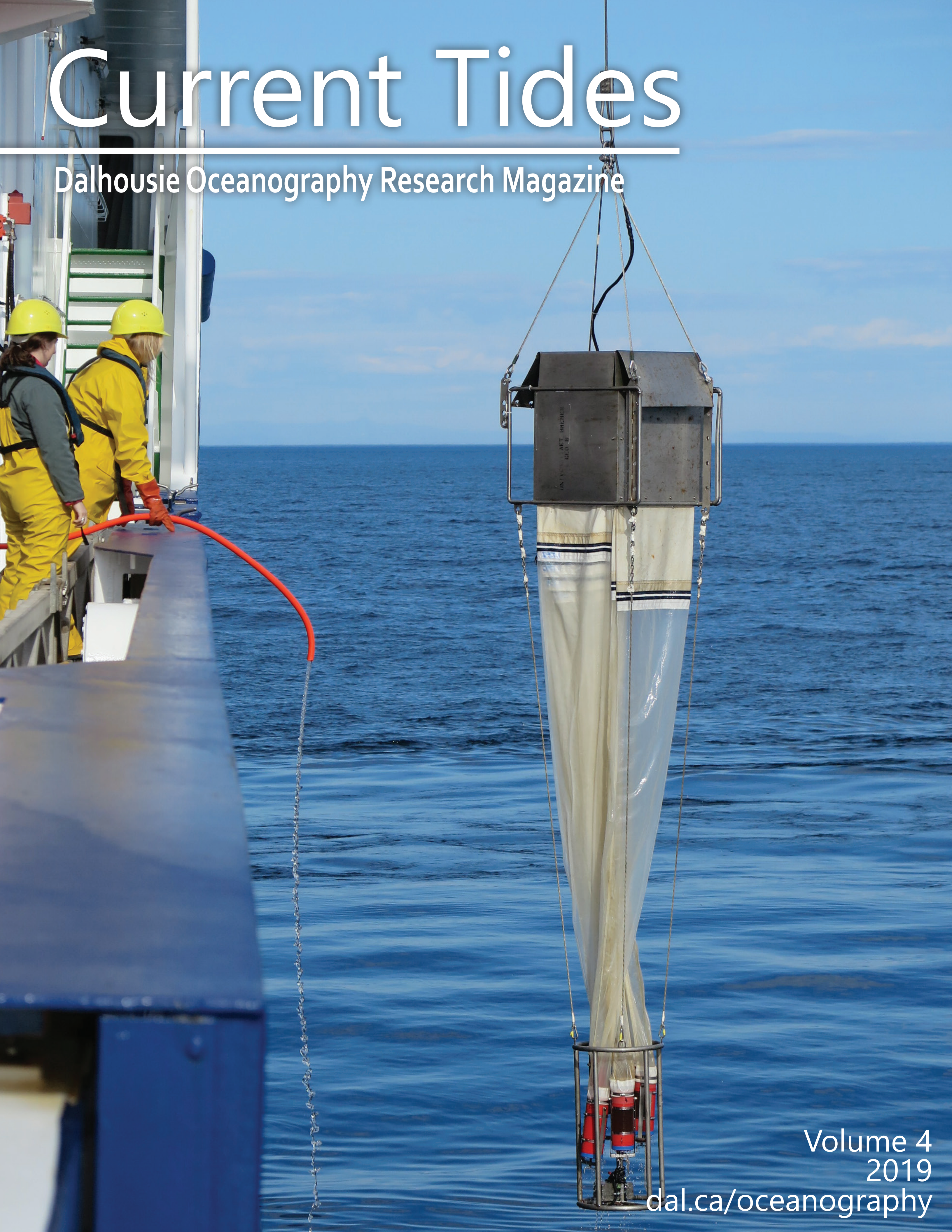

Current Tides

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Current Tides

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A Letter From the Chair

I was a bit bemused when *Current Tides* Editor-in-Chief, Tristan Guest, asked me whether I would once again write this "Letter from the Chair" for the fourth(!) issue of *Current Tides*. Naturally, I agreed, because this student-invented, student-run publication is a gem that communicates to a general audience the breadth and the importance of research pursued by students in our Department. My bemusement arose not from the task, but the timing. I simply had trouble reconciling with the fact that two years had indeed passed since the publication of the last issue. Reflecting on those two years, I realise that many familiar faces have gone on to new adventures, academic and otherwise, while new faces have joined our team of ocean researchers. Old research initiatives have been completed, and new ones have begun. These changes remind me in a tangible way of just how exciting a time it is to be an oceanographer at Dalhousie.

Reading this issue of *Current Tides* fills me with hope for the future, as the students continue the tradition of conveying the passion and excitement surrounding their efforts to confront some of society's most pressing ocean challenges. The articles highlight the role of new technologies in addressing issues of ocean conservation and sustainable use of ocean resources. Krysten explains how computers can simulate the tracks of fluid parcels from different water masses on the Scotian Shelf and how these simulations will help us to anticipate how the shelf ecosystem may change in coming years. Hansen provides insight into how we are learning to listen to the ocean, which promises to improve our ability to track and protect endangered large whales. JP takes us north, to the very edge of the ice, where increased summer melting is expanding access to northern waters. This expansion, however, comes with increased risk, as wave energy increases in newly open waters. Stef turns the figurative pages of Earth history stored in marine sediments to reveal a record of invasion of "light" carbon from fossil fuels into the ocean. Meghan tells a comical tale of taming a hovercraft that will allow her to map critical habitat in shallow water. Anne describes new efforts to map lobster habitat on a scale that is relevant to inshore fishers, while Ian explains how low-cost drone technology will develop our abilities to anticipate future rates of erosion of cliffed coastlines. Finally, Reid, Rhyl, Rory, and Nan explore the potential and pitfalls of nourishing mass-cultured phytoplankton with our wastes.

Congratulations to Editor-in-Chief Tristan Guest, the editorial staff and the designers for producing this edition of *Current Tides*.

Bravo Zulu!

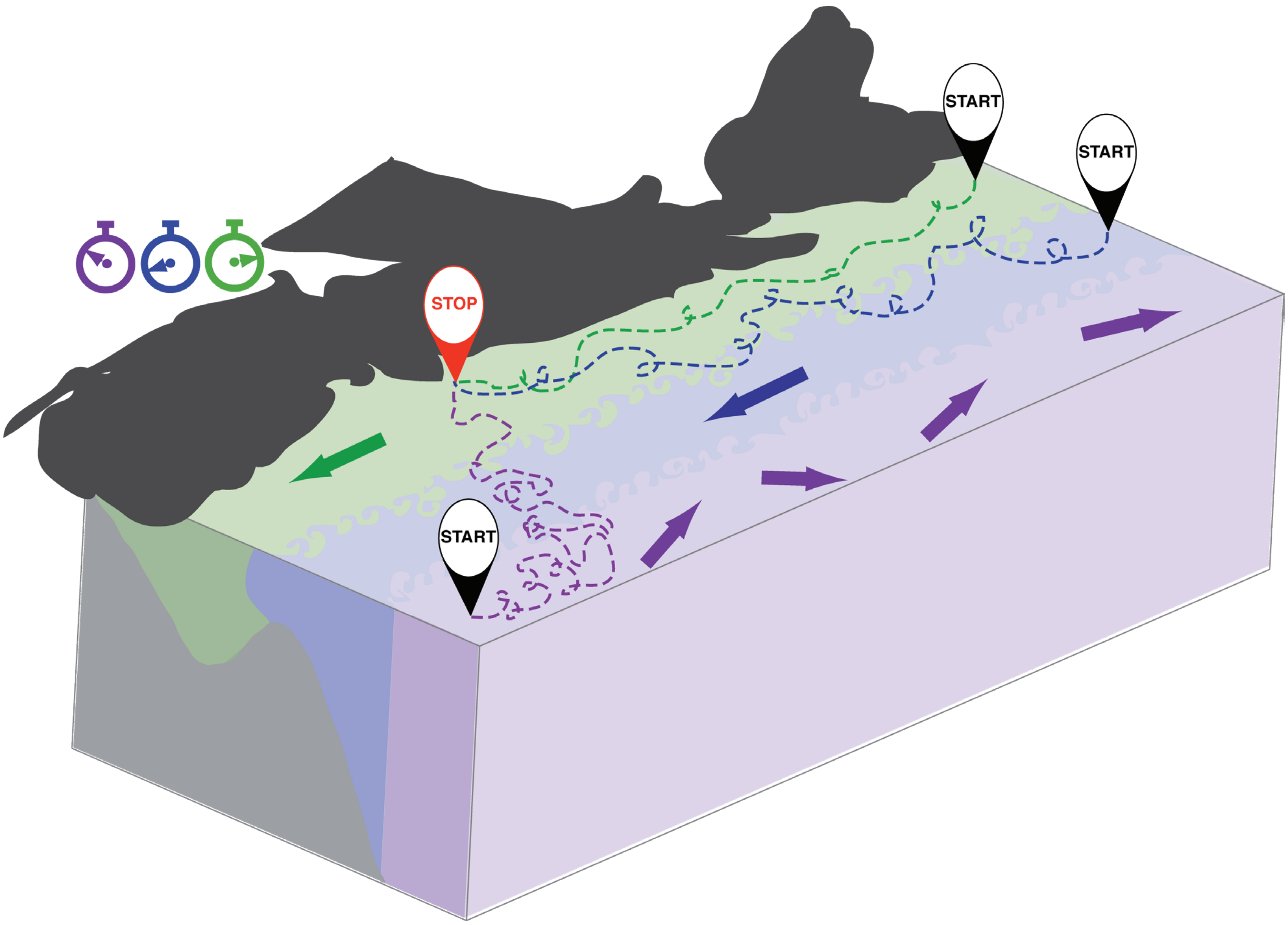
Paul Hill
Chair of the Department of Oceanography

Contents

Tracking the Ocean's Biogeochemistry: Just One Click Away!

A numerical modelling study of Scotian Shelf carbon dynamics

Krysten Rutherford



Labrador Sea water (blue) acts like a wall along the shelfbreak of the Scotian Shelf, inhibiting both the movement of Scotian Shelf water (green) offshore and slope water (purple) onto the inner shelf. As a result, it takes a long time for slope water to make its way to the inner shelf, particularly in comparison to the quick along-shore movement of the Scotian Shelf water.

With more and more stores turning to online shopping and two-day delivery, our society has become incredibly engrossed with shopping at the click of a mouse. Technology has evolved so we can now track our coveted order as it finds its way across the country and inevitably gets stuck at the post office two blocks from our house for 48 hours (sadly, this is a true story). But what if we could emulate this approach to better understand the ocean and its various components, like dissolved gases and phytoplankton?

Oceanic biogeochemistry is the important area of science linking the biology, geology and chemistry of marine environments. Biogeochemical properties vary throughout both space and time, and are unique to their starting location. Just as we know that water off the coast of Mexico is warmer than the water off the coast of Newfoundland, we also know that water off the coast of Mexico will have different biogeochemical signatures than that off the coast of Newfoundland. For example, the warm subtropical water off the coast of Mexico would likely have low oxygen and high carbon concentrations, whereas the cool Arctic water would be higher in oxygen. We would also expect that different creatures breed and live in different oceanic environments. As waters circulate throughout the ocean, they carry with them these unique biogeochemical signatures. So, rather than tracking Amazon parcels, my research focuses on tracking the evolution of oceanic biogeochemistry and how different seawater components are transported from one location to the next via the ocean's circulation pathways. I specifically study the coastal ocean off Eastern Canada, where the cool Arctic water exiting the Labrador Sea (the Labrador Current) meets the warm and salty subtropical water from the Gulf Stream. Many of the chemical dynamics and biological activities on the Eastern Canadian shelves are reliant on a specific balance between these water sources.

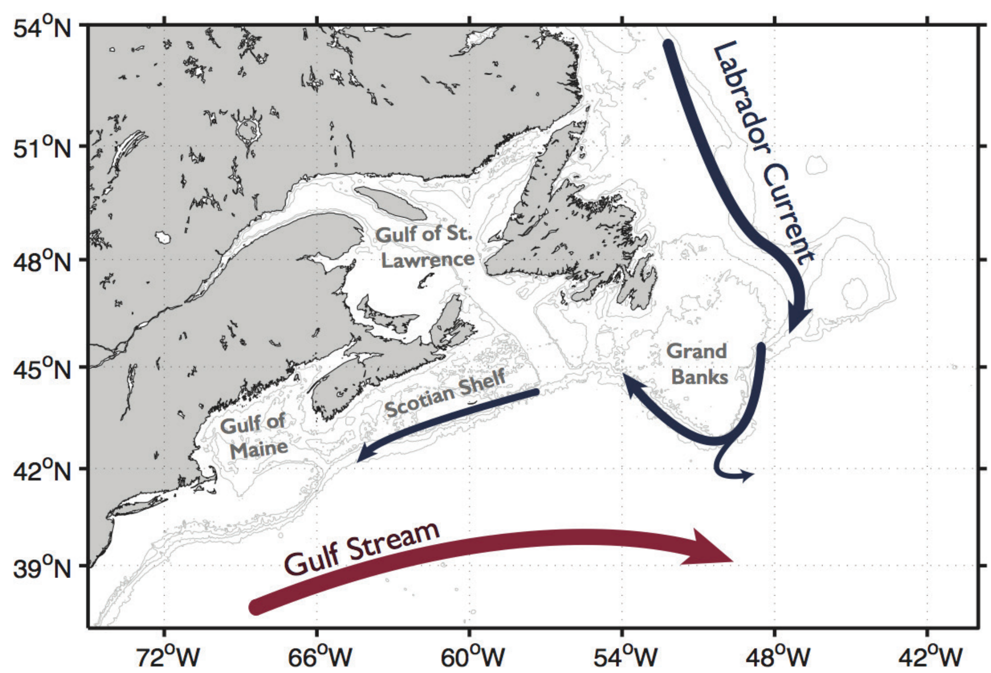
One of my aims is to understand the carbon dynamics of the Eastern Canadian continental shelves, including carbon usage during biological production and carbon transport timescales and pathways. Most people have heard about how greenhouse gases are being emitted into the atmosphere, driving an increase in atmospheric carbon dioxide (CO_2). But what we often don't hear is how this is affecting the ocean. At the air-sea interface, gases can move between the two media, going from a region of high concentration to low concentration (kind of like the ocean is breathing). In other words, if the atmosphere has a comparatively high concentration of a gas, such as CO_2, then we observe that gas transferring into the ocean. As we increase CO_2 in the atmosphere, the ocean absorbs more and more of it, which could have many detrimental effects, including ocean acidification. It is therefore incredibly important to understand the current state of carbon cycling and transport so that we can begin to predict how our oceans will react to a changing climate.

With increased human activity impacting the global oceans, we are also expecting a potential shift in the important circulation structure off Eastern Canada, which would have large implications for biogeochemical processes and ultimately local ecosystem dynamics. Recent studies have predicted that we will see a rebalancing of these water sources, with more warm and salty subtropical water on the continental shelves, which is indicative of important circulation changes. Such a rebalancing will likely lead to low oxygen, shelf-wide acidification and a complete change in the biological community structure. Overall, we are expecting to see climate change affect the northwest North Atlantic in many different and likely compounding ways.

The math behind it all

When most people hear that I study oceanography, they immediately ask about the whales, plastic pollution and research cruises I get to go on. Although these are exciting and important aspects of oceanography, I do a different type of oceanography that involves a lot of programming and coding. Specifically, I work with a 3-D numerical model of the northwest North Atlantic Ocean. The best way to think of a numerical model is like it's a simulation-based computer game: the player provides input, and the game progresses based on a set of rules in an emulation of real life. Numerical models of the ocean simulate what's happening in the real ocean using mathematical equations as the rules, and different variables as player input.

Numerical models are important when studying the ocean because it is just so vast. Although we do our best to sample the entire ocean, we have to consider three important limiting factors: the size of the ocean, the difficulty in reaching particular locations in certain seasons, and the time, money and resources needed to sample at regular time intervals throughout the entire ocean. In other words, it's nearly impossible to have good sampling resolution throughout both space and time. Resolution is the gap between samples; for example, a sample every 5 kilometres in space or 30 minutes in time. When sampling



Map of the northwest North Atlantic. Here, the Gulf Stream carries warm and salty subtropical water northward. The Labrador Current carries cool Arctic water southward, around Grand Banks and along the shelfbreak of the Scotian Shelf.

the ocean, resolution is often quite low, with tens to thousands of kilometres between sample points and sometimes only one sample a month, if we're lucky. Imagine trying to guess what the weather will be in Halifax, Nova Scotia on January 31st based on the weather in Fredericton, New Brunswick on January 10th. Seems pretty impossible, right? That's why we use numerical models: we use mathematical equations to interpret between the sampling points we do have to gain a fuller and more detailed understanding of what's happening in the real ocean.

Attaching the tracking devices

The next big question is: how exactly can you effectively track the incredibly massive and expansive ocean?

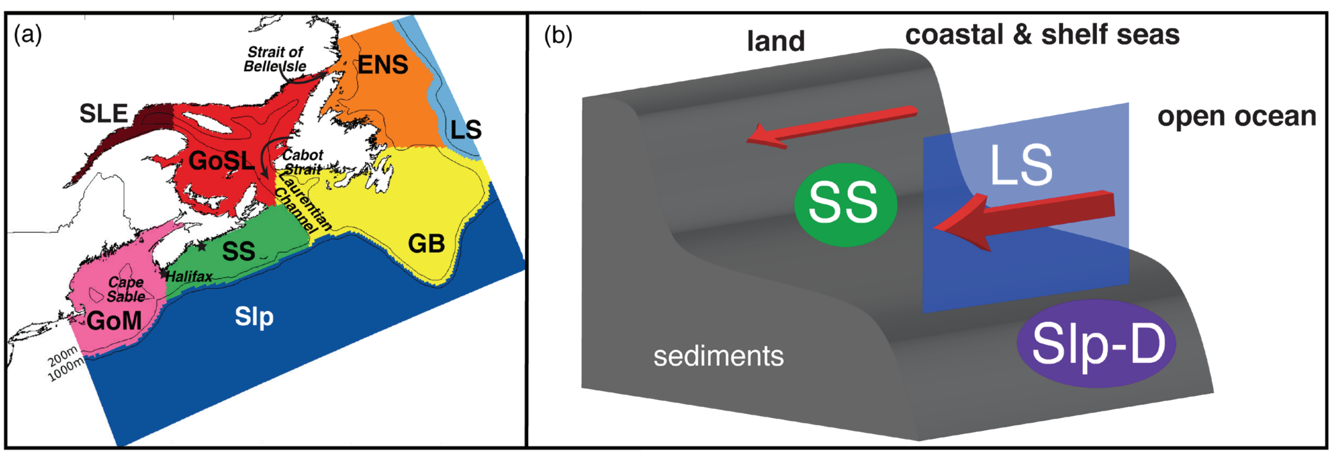
There are actually many ways that oceanographers track ocean circulation, mixing, and biogeochemical transformations, and the main tools needed are called tracers. Tracers come in many different forms, each with unique properties and applications. Although there are ways of using tracers in the real ocean, I implement and track tracers in a numerical model of the northwest North Atlantic (see figure, below left, for the region our model encompasses). In our numerical model, we have made use of passive dye tracers (in other words, tracers that cannot undergo any chemical reactions or modification, but simply move throughout the modeled ocean) and age tracers (I'll explain this a bit later on) to track different properties of the ocean here.

Let's first focus on the passive dye tracers. Essentially, passive dye tracers let us paint the water in our model different colours so that we can track where and how fast water is moving throughout the region by assigning different colours to different source waters. Since we have high resolution in our model, both throughout space and time, we can get a fairly complete picture of how water is traveling. Visually, we track the different transport pathways by tracking the different colours (think if you had a live, interactive map of where the delivery van was with your package). Mathematically, we can calculate quantities like flushing times (how long, on average, water is spending in specific regions) or mass fractions (the fraction of each dye at specific locations).

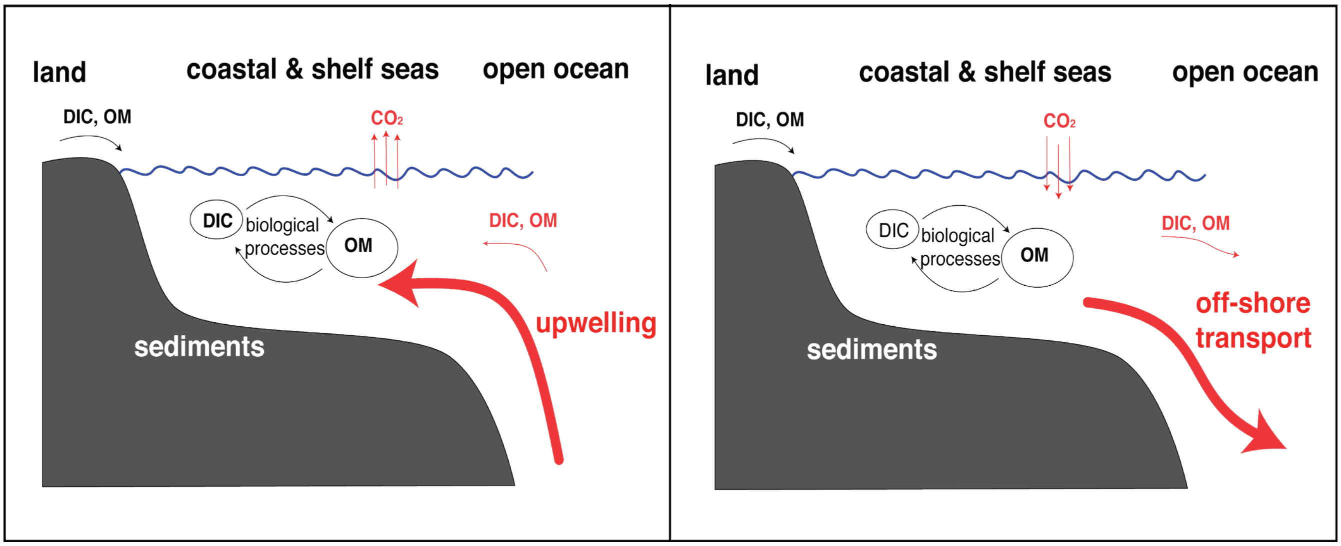
Altogether, we can use these tracking techniques to better understand the circulation in the region and how this might impact important biogeochemical processes.

The arrival and unboxing

The best part of ordering a package online, of course, is its arrival! It's like your birthday, but any day of the year. That's exactly how I feel whenever I get results back. When running model simulations, it can take at least a couple of days to get results back from the computer cluster we run on (and this of course assumes I don't run into any hiccups along the way, which is never the case). Needless to say, getting results back is the oh-so-sweet reward for many hours spent coding.
One of the key results from implementing the dye and age tracers in our model is understanding the dominant structure of the currents off the coast of Eastern Canada. For example, the waters starting on the Scotian Shelf move rapidly southward into the Gulf of Maine, whereas the deep slope water remains off shore and doesn't travel onto the shelf here (see figure, below right). The deep northern waters travel southward along the shelfbreak, acting as a wall inhibiting the direct movement of waters onto or off of the Scotian Shelf . There is some movement of these deep slope waters onto the shelves through deep channels, but this is very minimal. We only note large contributions of this deep slope water near the shelf break on the Scotian Shelf and throughout the entire Gulf of Maine. Farther inshore on the Scotian shelf, we note a large influence of Gulf of St. Lawrence waters, indicated by red dye here, again with northern-originating waters having a large influence as



(a) Map of model location, each colour indicating the starting location of different dye tracers. (b) Schematic of Labrador Sea (LS) dye acting like a wall, keeping the green Scotian Shelf (SS) dye on the shelf and the purple deep slope waters (Slp-D) off the shelf.



DIC (or carbon) and OM (or organic matter) undergo biological processes, gas exchange with the atmosphere, and transport at the land and open-ocean interfaces. At the coastal-open ocean, two important transport processes could occur: (1) upwelling, bringing carbon rich water onto the shelf or (2) off-shore transport, carrying DIC and OM to the subsurface open ocean.

well. Overall, this tells us that cool arctic water combined with riverine water from the Gulf of St. Lawrence play a dominant role in defining the biogeochemistry on the Scotian Shelf, with less influence from the warmer and saltier slope water.

So how does this relate back to those carbon dynamics we discussed? Well, part of what underlies carbon dynamics are circulation features. Many studies have looked at global continental shelves and have classified these shelves as either sources of CO_2 (that is, they tend to have excess CO_2 and are releasing it to the atmosphere) or as sinks of CO_2 (they tend to have less CO_2 and take up CO_2 from the atmosphere). In general, shelves that have many upwelling events, which means that carbon-rich water from the deep ocean is brought up to the surface ocean at the coast, have high CO_2 concentrations and therefore outgas CO_2 to the atmosphere (see figure above). Shelves that tend to be thought of as sinks of CO_2 are often thought to have a "continental shelf pump". This means that, as CO_2 invades the surface layer of the shelf waters, it sinks and travels across the shelf break to the sub-surface open ocean. By implementing the dye tracers in our regional model, we are able to show that neither of these mechanisms occur for the Scotian Shelf. We see little transport across the shelf break itself due to the Labrador Current, and instead observe direct along-shelf transport supporting large outgassing near-shore and much smaller fluxes elsewhere on the shelf. If over the coming century we see a decrease in the strength of the Labrador Current, as hypothesized by recent studies, we will likely see a large change in the carbon dynamics on the shelf region here, which is the important next step of my PhD research.

The big picture

Tracking the ocean's circulation has never been more important. As climate change progresses, we are expecting to see a total shift in the circulation of our oceans, especially at the dynamic region I study in the northwest North Atlantic. As the circulation changes, we will undoubtedly see changes to the biogeochemistry, including everything from copepod population restructuring to the shelf-wide carbon dynamics and acidification of our oceans. Now if only tracking the ocean was as easy as clicking "Track Parcel" online! ■

This research was funded by the Marine Environmental Observation, Prediction and Response Network (MEOPAR), and the Nova Scotia Graduate Scholarship (NSGS).

Krysten Rutherford

Growing up in the era where "climate change" were the buzzwords on many people's lips, Krysten always knew she wanted to work in the environmental sphere. Her goals have always revolved around exploring her passion for the environment while making some strides towards better understanding and hopefully stopping the many negative effects us humans are inducing on the world. Originally hailing from Ontario, Canada, Krysten spent most of her time by lakes and in forests instead of by the ocean. However, she has always been drawn to the mystery and expansive wonder of the ocean. Although she took a relatively indirect path to studying the ocean, first getting her BSc in Engineering Chemistry at Queen's University, she is now happily located in Halifax, NS working on her PhD under the supervision of Dr. Katja Fennel.

Ocean Eavesdropping

Using sound to find whales

Hansen Johnson

A right whale at the surface, photographed during a 2019 research cruise in the Gulf of St. Lawrence. Photo: Kelsey Howe, New England Aquarium.

Ship strike, fishing gear entanglement, noise pollution, and climate change threaten the survival of all large whale species. In the Northwest Atlantic, 'large whales' refers to fin, humpback, right, sei, and blue whales. Right whales often receive the most research and media attention, but all of these species are in trouble. We know there are fewer than 411 right whales left on the planet. We don't have accurate population estimates for blue or sei whales, but we suspect they also number in the low hundreds. Fin and humpback whales are doing slightly better, but are still listed as 'special concern' (not endangered, but still vulnerable).

Protecting these species requires management measures aimed to reduce or remove threats. Such measures might include re-routing ships around a feeding habitat, or closing areas to certain fisheries at particular times of year. There are many ways to mitigate risk, but nearly all of them require precise knowledge of where whales are, and which areas are most important for their survival.

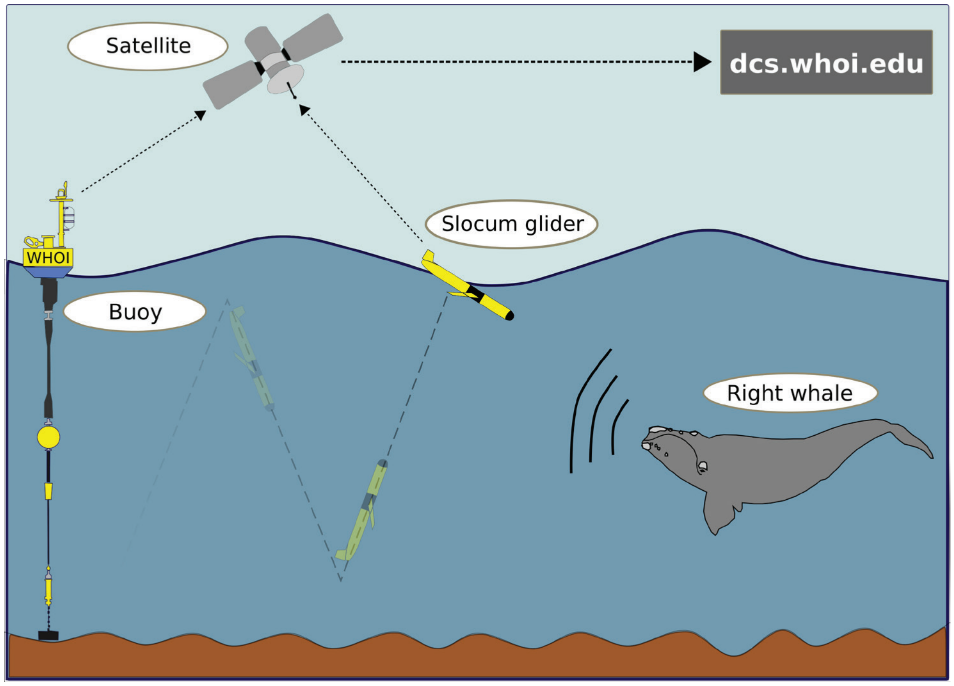
Sending out observers on ships and planes to locate a few hundred right whales somewhere between Iceland and Florida is like trying to find a needle in a stack of needles – it's incredibly difficult. Sound can help. Whales use sound to communicate over long distances. We can eavesdrop on whales' conversations to figure out where they are and when. This eavesdropping has developed into a scientific field called passive acoustic monitoring, or PAM for short.

Whales and sound

Sound can move very efficiently underwater. For example, under the right conditions, one blue whale calling in Hawaii might be heard by another on the California coast. For this reason, dolphins and whales (and many other ocean creatures) have come to develop sensory systems that primarily rely on sound rather than light. Both whales and dolphins use sounds to communicate. Dolphins also make 'clicking' sounds to image their environment through a process called echolocation. They can gauge distance to objects by listening for the echoes of their clicks. It turns out that humans can also be taught to echolocate, but that's a different story.

Not surprisingly, we know a lot about the sounds of the small whale and dolphin species that we can keep in captivity. When you move beyond the tank and into open water, as you must do for large whales, studying sounds becomes much more difficult. We've learned that all large whales make sounds, and have even identified some specific calls or patterns of calls that we can associate with a particular species.

Whale calls vary dramatically depending on the species. Humpback whales call constantly at certain times of year. Their calls sound similar to bird song in slow motion. Fin whale calls are quite different. They repeat the same tone again and again for hours or even days at a time. The pitch of their calls is too low for our ears to detect, so we might perceive it more like a heartbeat rather than a sound. Right whales have a unique calling behaviour. They're kind of like Wild West outlaws – they whistle once in awhile on the trail, and then have a crazy gun-slinging hootenanny when they hit the town.



Near real-time passive acoustic monitoring of large whales with a Slocum glider and moored buoy. All results are posted online at dcs.whoi.edu.

Ocean eavesdropping

Using PAM as a tool to detect whales is incredibly powerful. We can build small, inexpensive, low-power, self-contained systems that can record audio for long periods of time, and deploy them in places where we want to monitor for whales. Then we go home to relax in a nice warm, safe place somewhere on land while the recorder listens 24/7 for whales. Compared to traditional visual monitoring, PAM is cheaper, safer, and often more efficient.

Typical PAM methods only provide information on the presence of whales after the recorder has been (successfully) recovered. That's a big problem if you want to use PAM to inform reactive or dynamic conservation strategies, such as diverting vessels away from a group of whales, or adjusting fishing activities when whales are nearby. All these strategies rely on getting information right away, or in real-time.

A few enterprising groups have developed PAM systems that deliver information in real time, or close to it. Scientists at the Woods Hole Oceanographic Institution have made one such system called the DMON-LFDCS. The 'DMON' is an underwater microphone system, and the 'LFDCS' is software that detects whale sounds and sends that information back to shore over satellite. This detection information is then displayed online (dcs.whoi.edu) where it can be reviewed for the presence of different species. Validated detection information is then publically shared on a variety of platforms, including Dalhousie's own WhaleMap (whalemap.ocean.dal.ca), to inform risk mitigation.

Part of the brilliance of the DMON-LFDCS is that it can be slapped onto almost any platform that can provide power and a satellite link. It's been put on a number of moorings and vehicles, but is most commonly used on a one metre long, torpedo-shaped underwater robot called a Slocum glider. Don't let the shape fool you – it moves about six times slower than you walk. But what it lacks in speed it makes up for in persistence – the Slocum glider can swim up and down through the water, recording sounds and other ocean data, for weeks to months at a time (see figure above).

Knowledge gap: detection range

One of the pervasive challenges in passive acoustic monitoring, especially for large whales, is that it is extremely difficult to know how far you can hear calls underwater. These whales make very loud, very low calls that, under the right conditions, can propagate tens to hundreds of kilometres. The range over which these calls can be detected depends largely on the type and quality of the call, the physical properties of the water (depth, temperature, salinity, etc.), the type and structure of the bottom, ocean noise levels, and more.

Even though it's complicated, it's very important to understand how far we are able to detect whales if we hope to interpret our monitoring results correctly. For example, if we alert a ship to nearby whales, it is important that we also give an indication of how far the whales might be so the ship can be sure to avoid them. With that in mind, we devised an experiment to measure the detection range of the DMON-LFDCS on both mobile (Slocum glider) and fixed (mooring) platforms.

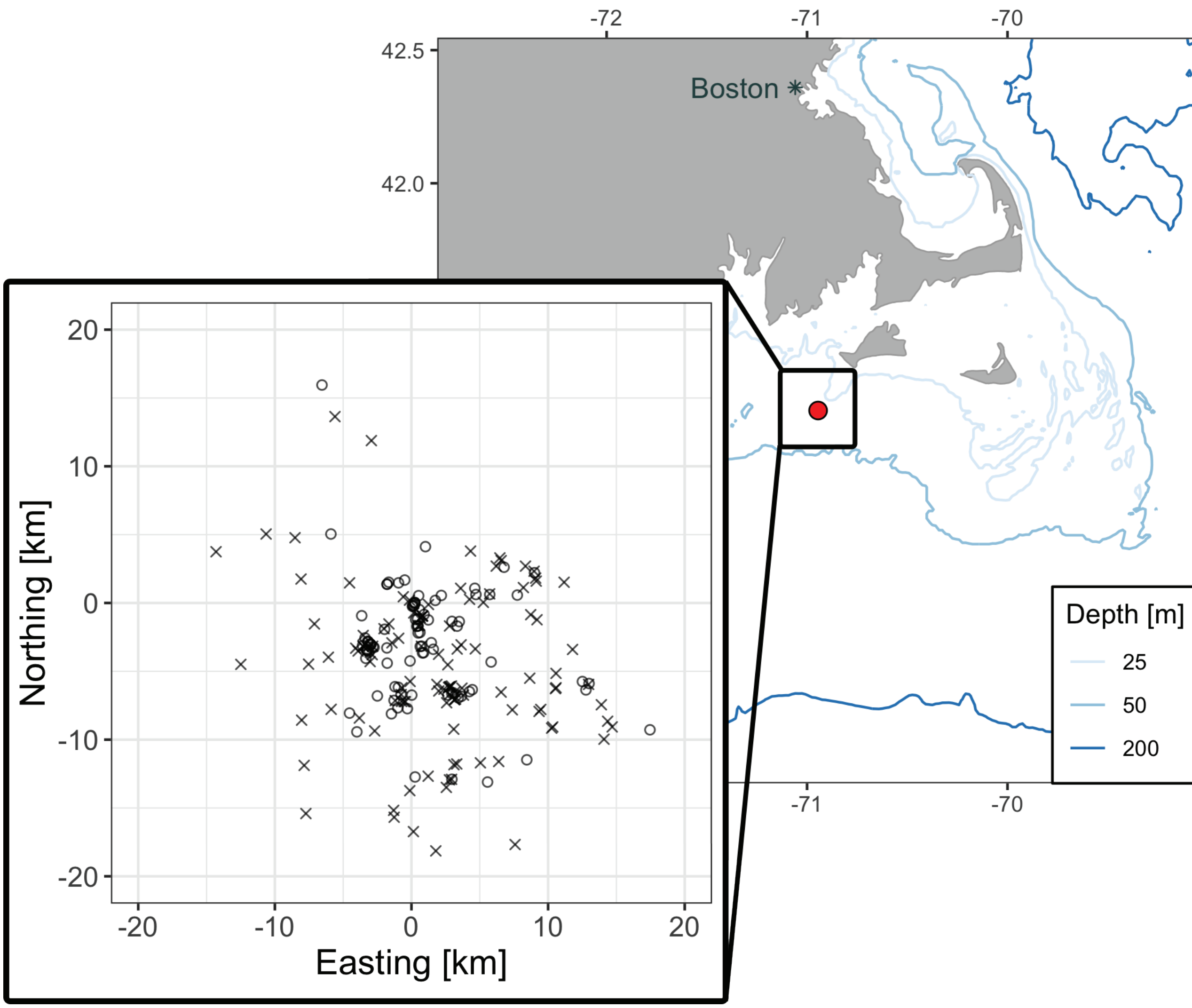
Measuring detection range

The first step was to deploy a glider and a mooring in the same place at the same time in an area where we were likely to detect whales, especially right whales. We also needed to have a way to estimate the position of (that is, 'localize') calling whales. To do that, we also deployed an acoustic array alongside the glider and mooring. An array is basically a long string of underwater microphones that record underwater sounds simultaneously. Arrays have several advantages over single-microphone systems. In this case, the array allowed us to exploit minute differences in the timing and strength of sounds recorded on each microphone to estimate the location where each sound was produced.

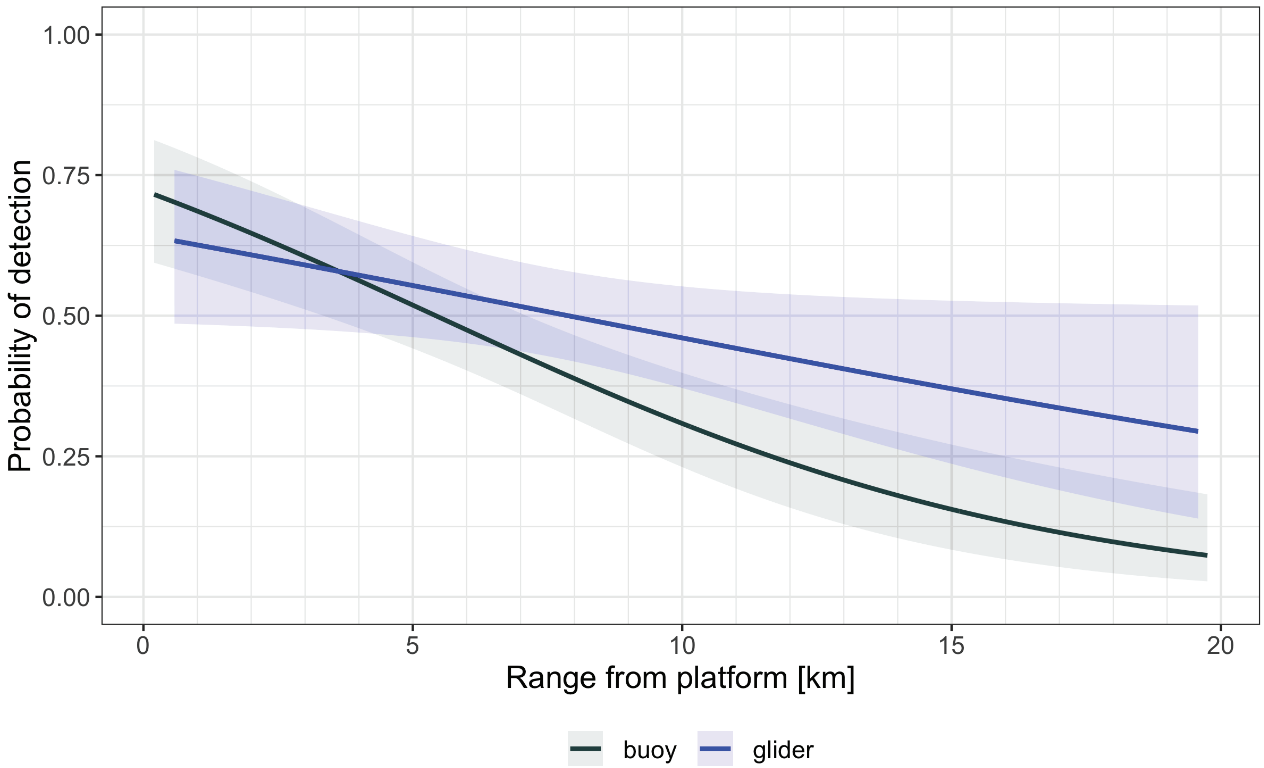
We put the array and a glider out near an existing mooring about 15 kilometres southwest of Martha's Vineyard, USA (see figure below) in February of 2017 for about a month. A storm blew in just as we were about to get the gear. The 5-metre waves tangled the array into a spaghetti-like mess. Fortunately, a team of divers was able to find the mangled array and help us get it back home.

I downloaded the audio data from all three systems and started the analysis. To my immense relief, there must have been a right whale party nearby – the data were full of calls! The first steps were to localize all the calls received on the array and calculate the distances from each platform to the calling whale. Next, I compared the calls on the array with those heard by the glider or mooring. When the glider heard the call, I gave that call a score of 'O', and when it missed the call it got a score of 'X'. The figure below shows those results. If you look closely, you may be able to see more calls detected (O's) close to the array, and more missed calls (X's) further away, but it's difficult to tell by eye.

We used a statistical tool called a logistic regression to quantify the relationship between the probability of detection and range. The results suggest that the glider was able to consistently (more than half the time) detect right whale calls at ranges of about 8 kilometres, while the buoy is only listening out to a little over 5 kilometres (see figure opposite).



Study area 15 km SW of Martha's Vineyard, MA, USA, where glider, array, and buoy were deployed in February 2017. The inset shows the positions of all right whale calls localized during the deployment, with O's and X's indicating calls that were detected or missed by the buoy, respectively.



Logistic regression analysis showing the estimated probability of detection for the buoy (black) and glider (blue). The shaded regions provide 95% confidence intervals around each regression.

So what?

Now that we've characterized the performance on the two platforms, we can use this information to try to improve the DMON-LFDCS. For example, it's unclear why the detection range of the buoy appears to be substantially less than that of the glider. It could be that the movement of the mooring lines in the current and waves creates more noise, which makes it more difficult to detect faint calls. The glider is free floating, so may not fall victim to the same noise issues. This is something that we plan to test very soon, and could have important implications for what types of platforms we choose to use in future deployments.

One limitation of this study is that the detection ranges we calculated here really only apply to the specific conditions (time and place) of this experiment. For example, we cannot simply use these results to figure out the detection range of a glider on the Scotian Shelf in June. An important next step will be to generalize these results so they can be applied to upcoming missions across the NW Atlantic. ■

This research was funded by the Nova Scotia Offshore Energy Research Association (OERA) and the Massachusetts Clean Energy Center (MassCEC). Support for the author was provided by a Vanier Canada Graduate Scholarship, Killam Predoctoral Scholarship, Nova Scotia Graduate Scholarship, Dalhousie University President's Award, and Natural Sciences and Engineering Council (NSERC) Michael Smith Foreign Study Supplement.

Hansen Johnson

Hansen is a doctoral student in biological oceanography at Dalhousie University. His thesis work broadly seeks to address knowledge gaps in baleen whale acoustic and habitat ecology in the Northwest Atlantic, with the goal of improving monitoring and conservation outcomes. It relies heavily on interdisciplinary collaborations and a combination of new and standard approaches such as passive acoustic monitoring from autonomous platforms, shipboard and aerial visual surveys, zooplankton sampling, and more. He came into this line of work as a means of uniting his passion for natural science and music. Much of his spare time is spent on his sailboat.

Do Waves Fall Flat Under Sea Ice?

The clash of navigation's two greatest hazards

Jean-Pierre Auclair

Aerial photograph of the marginal ice zone showing the progression from open waters (top left) to compacted small floes (left) and larger ice plates (top right).

The quest for the Northwest Passage, a route between Asia and the heart of the western world through the Canadian Arctic Archipelago, has a long history of heroism and tragedy. Aside from the explorers looking for this marine way and the small local populations with generations of experience guiding them, arctic waters were wisely avoided up until recently. Sea ice is, after all, a major hazard for the average ship.

With warmer summers and our ever growing hunger for resources, humanity is looking further north and expanding what are considered navigable waters to seas that have always been considered dangerous. The rapidly warming climate at high latitudes has made certain routes manageable enough to be developed. In 2007, one of the record low years for sea ice extent, the Northwest Passage was nearly ice-free for several weeks. After being a fairly quiet environment, the Arctic is now playing host to a variety of vessels including even tourist cruise ships.

Weather patterns in the Arctic have tended to generate growing areas of open water north of eastern Russia and Alaska in the recent past. Larger areas of ice free water allow the wind to act over a greater distance and force significantly larger waves in the Arctic ocean. These newcomers to the Arctic, waves and commercial ships, are motivating a flurry of activity in the forecasting community.

Historically, waves were a hazard only when ice was absent, and vice versa. Forecasts for waves and ice were thus performed independently. Afterall, a ship sailing from Europe to North America generally does not need to concern itself with sea ice any more than an icebreaker approaching the North Pole would need to consider waves. Icebergs may come to mind as an exception. Broken off pieces of glaciers up to tens or hundreds of metres thick and kilometres in size, they are tracked individually in a different forecast. Sea ice refers to frozen sea water rarely thicker than 10 metres. My research deals with sea ice in the marginal ice zone (MIZ): the icy area near open waters where waves also are important (shown in figure above).

Crushing ice and breaking waves

Currents, winds, waves and the pressure transmitted through the ice all contribute to moving sea ice. While wind and current patterns can span hundreds of kilometres, the force applied by waves is very local, pushing on scales that are hundreds of metres to a few kilometres at most. When subjected to all these forces with nowhere to go, ice can form stacks of rafted plates on top of one another, forming the thickest sea ice. This is common in the MIZ, where the changing sea surface and the strong push that waves deliver make it easier to stack ice floes on top of one another in a process called rafting.

It is easy to think of sea ice as a rigid lid on top of the ocean, especially since it can be metres thick. However, it is not entirely rigid and can break or even flex to support waves. Sea ice behaves more like a deformable plastic lid than an actually rigid one. It can be bent with some work. The faster this lid is bent, the more energy is spent. Short, rapidly oscillating waves thus tend to disappear faster than long, slowly oscillating ones. Around Antarctica, the large, long waves of the Southern Ocean have been observed propagating hundreds of kilometres under ice! In the Northern Hemisphere, waves do not grow as much because areas of open waters are smaller. These smaller waves may only penetrate up to a few tens of kilometres.

How far waves penetrate depends on the ice. The thicker it is, the more rigid and heavy it is, and the more quickly waves will lose their energy. The type of ice, either a collection of small pieces or one large continuous plate, will change the flexibility and how far waves can propagate before disappearing as well. The plot of wavelength versus distance (opposite left) shows an average prediction of how far waves of a given length can go in ice of a certain thickness before essentially disappearing.

With a broken cover, collisions between pieces dissipate the wave energy. Perhaps surprisingly, a continuous ice 'lid' can be worse at dissipating wave energy than a jumble of pieces. Bending this ice 'lid' may require more energy than lifting pieces, but like a bent piece of plastic, it can spring back into shape, giving energy back to the waves. Large enough waves can also break continuous ice into pieces of smaller and smaller sizes, increasing how much energy is lost by later waves. Understanding the interactions between waves and ice is still very much a work in progress. Many theories try to explain how waves lose energy and push ice, resulting in a wide variety of predictions. The main problem is obtaining good observations to test these theories. Wavy ice offers no sure footing!

A wild laboratory

Satellites have been a boon to the scientific ice community. Taking pictures of the Earth from space was one of the first things done by satellites, and ice is quite easy to spot – bright white on the deep blue ocean. This helped spur the development of the first computer models for ice in the late 1970s which remain the basis of today's forecasts.

While it is fairly easy to detect ice with a satellite, it is much harder to measure its thickness. For that, the best approach is to be standing on it. That, in itself, is a challenge since sea ice thrives in conditions that are difficult for humans to perform fieldwork. Nonetheless, icebreakers or expeditions on the ice have measured ice thickness. For safety reasons, however, this is mostly done on thick ice that is unlikely to break, not in the MIZ where the smaller floes and open, icy waters often make it too hazardous.

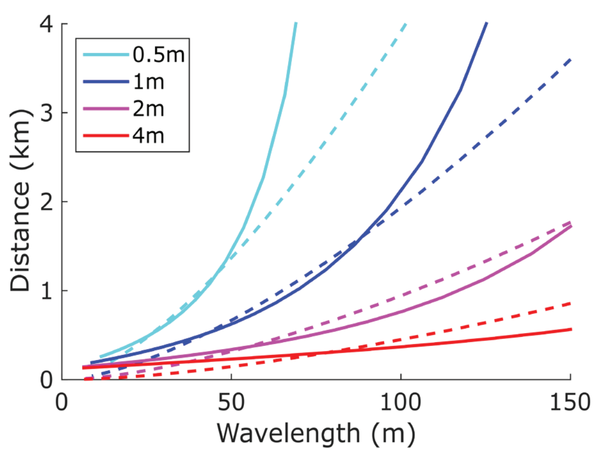
Very few people dare to venture out in the MIZ. Before the days of powered ships, ice canoes were used to maintain contact and commerce across the Saint-Lawrence River Estuary. This old means of transportation has been resuscitated recently, both as a sport for the most rugged and as a way to study the chaotic MIZ. In the Bic National Park, on the particularly well shaped and oriented (and quaintly named) Baie du Ha-Ha, a team of scientists from l'Université du Québec à Rimouski has maintained cameras, moorings and field measurement campaigns for the recent years in order to provide us with an observation set unlike any other, covering most of the variables we need to know.

Better forecasts for mariners

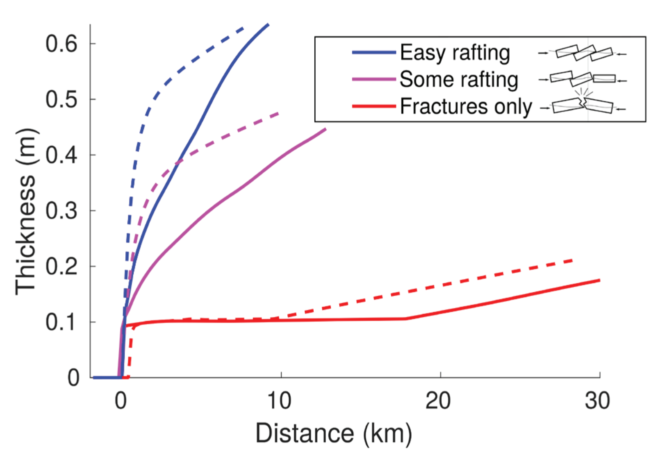
Weather forecasts have come a long way since the days of diviners and intuition. Scientific breakthroughs, and a lot of observations, have allowed us to predict quite accurately what will happen in the coming days and even provide an outlook of what we can expect next season.

The first big development of forecasting came from the capability to describe what the situation is right now and understanding how it will evolve. Computers have since allowed us to simulate the world and how it could change as predicted by our best scientific theories.

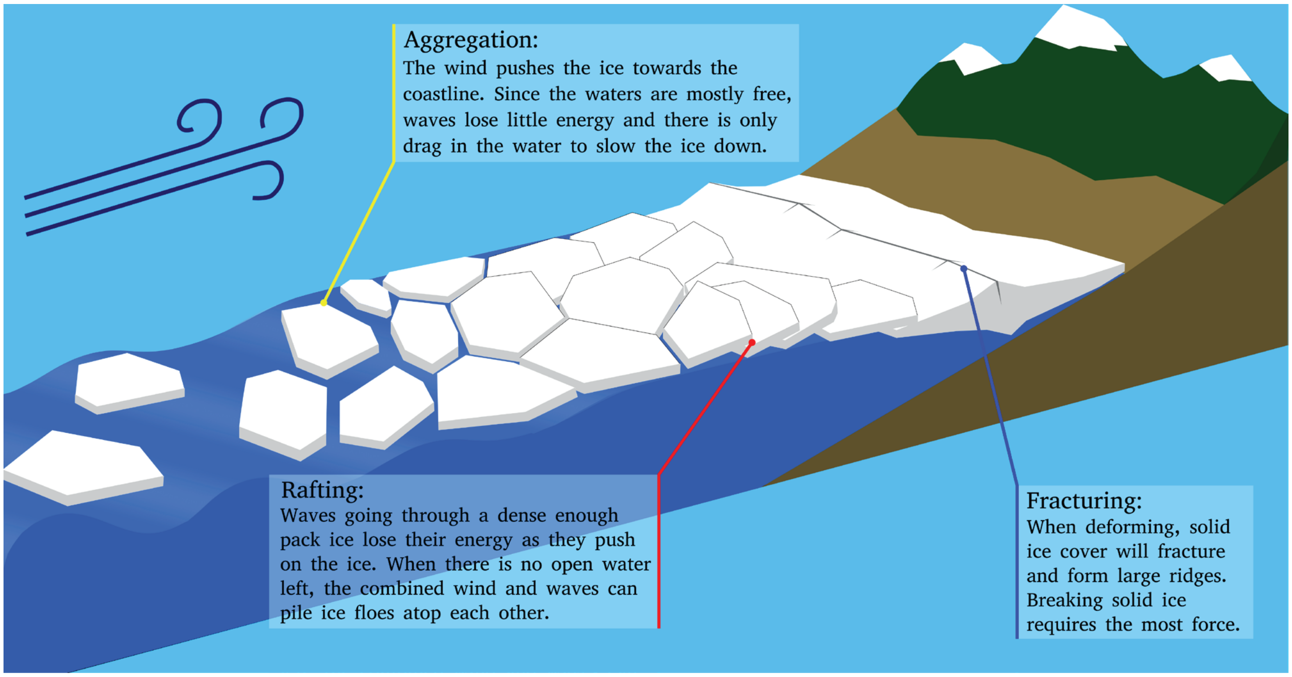
For me, improving the sea ice forecast means developing theories on how waves and sea ice interact in the MIZ, using those in a model to make predictions, then comparing those against observations. Since the field of forecasting sea ice and waves together is in its infancy, there is no one set of rules but rather a variety of plausible ones. There are two parts to my work. First, to select rules for the model. These define, for example, how waves weaken as they propagate in the ice or how ice resists pressure. Second, to build the model by using the minimum number of rules together to simulate what would happen in simple conditions. Using this model, we can try all the plausible rules and see which combination best reproduces what was observed. As an example, the distance versus thickness plot (below, right) compares three ways ice can respond



Wave energy penetration distance over a range of wavelengths and ice thickness for broken (--) or solid (-) ice cover.



Thickness profiles generated with a broken (--) or solid (-) ice cover for increasing ease of rafting.



Schematic of a simplified wave-ice model for the marginal ice zone. Graphic: Tristan Guest.

when it is pushed and how these responses affect ice thickness. First, we consider ice solid. In this case, ice needs to fracture to get thicker (red). We can make it unlikely to happen in the simulations (magenta) or more likely (blue). In the field studies, it was observed that ice thickens rapidly from the ice edge before reaching a constant value. We see the fastest increase in thickness with distance in the simulations with more rafting (blue), matching observations better. Conveniently, we also know that rafting is common for thin ice in waves.

Once the best combination has been identified, it can become our 'working theory': in this case, broken ice with easy rafting. With that, we can start looking at the impact of a variety of waves on ice of a variety of thicknesses and make predictions that are relevant to navigation. Most importantly, we can better forecast the movement of the ice edge and let ships know where they should be safe from encountering sea ice. For ships which do not avoid ice, like icebreakers, it is still interesting to know the thickness of the ice they will encounter as it will change the speed at which they can move.

These predicted wave impacts are the main contributions of my project. Eventually, the work done to understand which ruleset to use will enable the creation of a full model for both ice and waves together in a region or globally. Then, we can forecast everything at the sea surface every day like we do for temperature, winds, precipitation and much more in weather models. ■

This research was funded by the Marine Environmental Observation Prediction and Response Network (MEOPAR), a National Science and Engineering Research Council (NSERC) PGS-D scholarship, and Environment and Climate Change Canada through the Research Affiliate Program.

Jean-Pierre Auclair

Born on the south shore of the St. Lawrence river and raised within the oceanographic community of the area, it was a natural choice for Jean-Pierre to study the ocean. Straying from his original interest in his father's field of marine biology, he ended up attending McGill University in Physics. Motivated by the hurricane season of 2005, when greek letters had to be used for storms after exhausting the normal name list, Jean-Pierre left the world of particles, stars and advanced materials to focus on weather and the ocean with a specific interest in forecasting and interactions at the surface. His PhD project comes as a continuation of early work in sea ice modeling and an MSc on wave growth, and comes as a throwback to coastal, wintery, origins.

Looking into the Past to Better Understand the Future

Tracking anthropogenic carbon emissions through the fossil record

Stef Mellon

Since the beginning of the industrial revolution, carbon dioxide (CO_2) concentrations in the atmosphere have increased by almost 50%. Driven by human fossil fuel combustion and deforestation, this increase in atmospheric CO_2 causes Earth's atmosphere to act like a greenhouse, warming the planet. The oceans are natural storage reservoirs for this excess CO_2—at least 30% of emitted CO_2 makes its way from the atmosphere to the ocean, where it reacts with water to form carbonic acid. The resulting ocean acidification threatens organisms that form shells made of calcite, such as shellfish and corals. We know from this chemical reaction that ocean acidification will continue to occur as long as we emit CO_2, but understanding rates of change and predicting future impacts are difficult using currently available measurements. Modern observations that track oceanic CO_2 variations over space and time have been sporadic up until the last few decades.

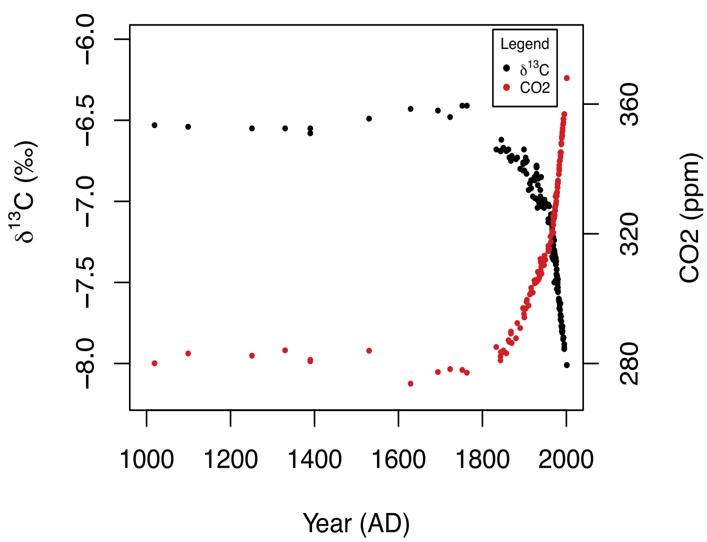
With limited time series measurements, how can we predict the impact that ocean acidification will have on ocean ecosystems? How will the increase in CO_2 impact fishing industries and the coastal communities that depend on them for prosperity? An important step in answering these questions is understanding how environmental conditions varied in the past. We need to understand natural climate variability so that we can distinguish human-caused trends from natural baselines. The study of past ocean climates, called 'paleoceanography', is essential for explaining present day ocean observations and the current climate trajectory within the context of Earth's natural climate cycles on longer timescales—from decades and centuries to even millions of years. My master's thesis made use of this approach to study human impacts on the carbon cycle of the Northwest Atlantic Ocean.

Digging through time

Like archaeologists uncovering human history, paleoceanographers look for clues preserved in the earth to piece together the history of Earth's climate. Where an archaeologist may discover clues about ancient human culture and biology from the remains or artefacts of long-lost humans, a paleoceanographer may determine the changes in concentrations of oceanic chemicals over time by analyzing microfossils found in seafloor sediments. Ocean conditions leave geochemical markers in many of the organisms that live there. For example, a cold, salty environment would leave a different geochemical marker than a warm, fresh environment. The technical term for these environmental clues are 'climate proxies', which by definition are measurable variables that correlate with climate variables of interest.

Isotopes as a proxy for the carbon cycle

Carbon isotope ratios are a notable proxy that are useful for studying CO_2 absorption by the ocean. Isotopes are forms of an element that vary in mass, due to differences in the number of neutrons. They are particularly useful in deciphering past conditions because a given isotope may be more sensitive to physical processes than other isotopes of the same element. For carbon, there are two stable isotopes—carbon-12 and carbon-13. Scientists report the ratio of these isotopes in $\delta^{13}C$ notation, which is the ratio of carbon-13 to carbon-12 relative to a standard reference material, multiplied by 1000, with units of per mil (‰, or parts per thousand). A negative $\delta^{13}C$ value, such as the pre-industrial atmospheric value of -6.4‰, implies



A 1000-year record of atmospheric CO_2 (red circles) and its $\delta^{13}C$ composition (black circles). These data were compiled from high-resolution ice cores at Law Dome (East Antarctica) and the South Pole. Data from Graven et al. (2017).

A gravity corer deployment in the Labrador Sea. Inset: A first look at a freshly retrieved sediment core. Photos: Dr. Markus Kienast.

that there is less carbon-13 relative to the standard material.

The lighter isotope, carbon-12, is easier for organisms to use during photosynthesis and is therefore preferentially absorbed into plant tissue. Consequently, the plant would have a $\delta^{13}C$ value that is lower than the surrounding environment. Following this logic, fossil fuels such as coal (essentially fossilized plants) are enriched in carbon-12 relative to the atmosphere. As we burn isotopically light fossil fuels, the carbon-12 enriched CO_2 is released into the atmosphere, and $\delta^{13}C$ decreases accordingly. This abrupt change in the isotope record is called an isotope excursion.

The Suess effect

The negative carbon isotopic excursion (that is, decreasing $\delta^{13}C$) in the atmosphere was first observed in 1955 by Dr. Hans Suess, and was thus termed the "Suess effect". Since CO_2 is absorbed by the ocean, we hypothesized that the Suess effect should be detectable in the carbon isotopes measured in surface water. But how do we measure $\delta^{13}C$ of the past ocean? The microfossils of choice are zooplankton called foraminifera, which calcify their shells in chemical equilibrium with the surrounding water, thus having the same $\delta^{13}C$. When the organism dies, it sinks down to the bottom of the ocean and is later covered by more sediment. Paleoceanographers go to sea on research vessels and deploy coring devices that penetrate the seafloor to collect sediment samples in long cylindrical tubes. These samples contain the foraminifera that have sunk to the seafloor over thousands of years at that location. They are layered chronologically through time, assuming the seafloor sediments haven't been disturbed.

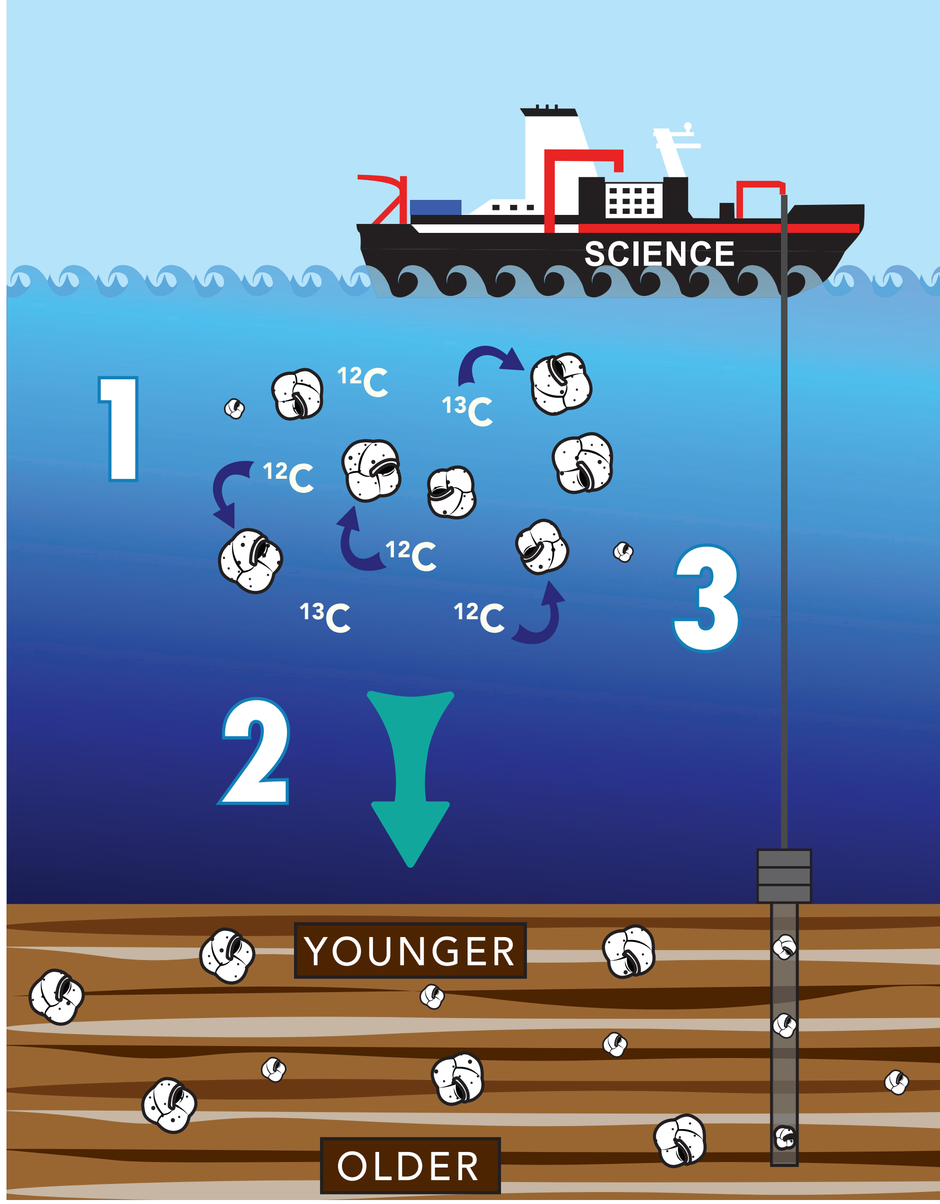
For my thesis, I sampled foraminifera from five sediment cores. The cores were collected from locations across the Northwest Atlantic with different oceanographic conditions, with the hopes of compiling an average $\delta^{13}C$ history that represents the entire region.

Space-time in paleoceanography

How do scientists know how old the sediment is? How do we get a time series climate record from a sediment core? We don't need to bring in Einstein's theory of relativity to link space and time at the seafloor, but we do need to derive mathematical models and make assumptions about the environment. To obtain a time series record, we need to develop a depth to time model based on age markers in the sediment. This process is a significant part of a paleoceanographer's research and was a key component of my thesis project.

The first assumption that can be made is that the top sediment is younger than the sediment below it. Therefore, the deeper you go down the core, the further back you go in time. There are many different methods for determining the age of sediment cores. Radioactive elements such as carbon-14 are useful because knowledge of decay rates and initial concentrations can be used to calculate absolute ages. You can use decay rates of other radioactive elements such as lead-210 to determine the rate at which sediment is deposited on the seafloor. Sedimentation rates, usually expressed in centimetres per year, are useful indicators when paired with absolute dates.

An interesting silver lining to human pollution is that we can actually age sediments based on levels of specific pollutants in the sediment. The peak of nuclear bomb testing in 1967 can be seen as a distinct spike in radioactive cesium-137 in the sediment. Mercury production proliferated in the mid-1900s and only declined in the 1990s, making it another useful age marker of modern sediments. These are a few of the many chemical markers that humans have left in the geologic record. Our mark as a species is so distinct that it has led geologists to initiate a new epoch—the Anthropocene.



The foraminifera form their shells from the surrounding dissolved carbon, and therefore keep the same isotope ratio. 2) After the foraminifera die, they sink down to the seafloor and slowly get buried by newer sediment. 3) Paleoceanographers collect long cores of sediment from a ship using a gravity corer. The structure of the sediment is preserved in these cores, such that younger material is at the top and older towards the bottom.

Sediment revelations

Using various dating methods, I applied age-depth models to the sediment cores through linear interpolation. Results revealed that the cores ranged in age from 100 to 4000 years old. Next, I needed to measure the $\delta^{13}C$ of the foraminifera present in the cores. This involved manually sifting through sediment samples under the microscope to look for the species of interest. This task is a bit like searching for a needle in a haystack, but measures can be taken to narrow down the options. Small particles of mud were removed by washing the sediment through a sieve, and the remaining particles were separated into different size ranges. I then examined the particles that fell in the foraminifera size range, and picked out enough specimens to measure $\delta^{13}C$ at each centimetre down the sediment cores.

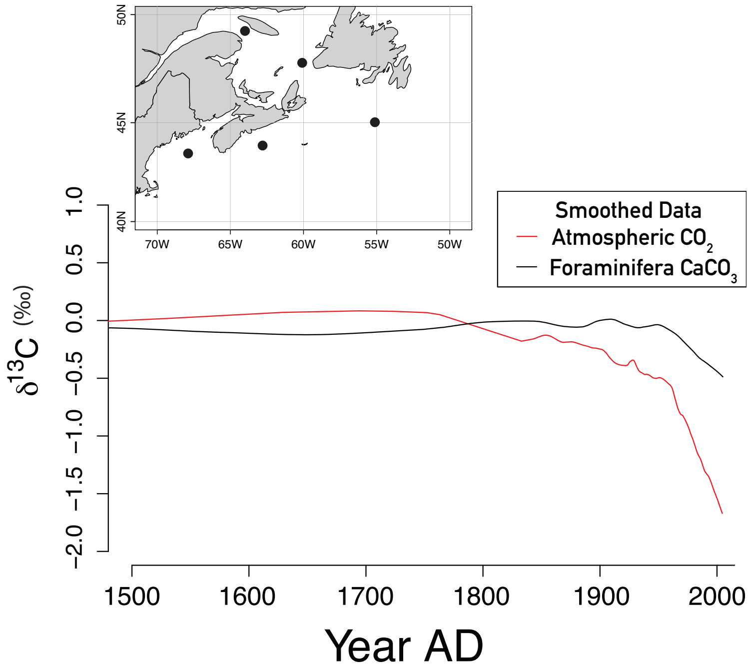
By measuring the $\delta^{13}C$ of the foraminifera found in the core, the end result is a time series of $\delta^{13}C$ representing the surface waters at each location the cores were collected. With these data, we can test the hypothesis that the isotopically light CO_2 from fossil fuel burning is entering the ocean and manifesting as the Suess effect.

The records reveal a pronounced Suess effect since the mid-twentieth century, lagging shortly behind the observed Suess effect in the atmosphere (see figure, page 18). This stark decrease in $\delta^{13}C$ is unprecedented over the time period covered by the sediment cores, highlighting that natural variability does not likely account for all of the observed trend. This result suggests that fossil fuel-sourced CO_2 is entering the ocean in the continental shelf region of Atlantic Canada and increasing the risk of ocean acidification.

New answers, new questions

So why is there a lag between the atmosphere and the ocean $\delta^{13}C$ records? It seems as we answer one question in science, a new one arises. There is a well-understood 10-year time lag between the $\delta^{13}C$ of the atmosphere and the ocean, due to the time it takes for these two pools of carbon to equilibrate their carbon isotope ratios. But this would not account for the full lag seen in my results. Could error in the age model be contributing? Potentially.

Even though it is a safe assumption that sediment is deposited sequentially with newer sediment laying above older sediment, there is a possibility that this order gets tampered with. The seafloor is teeming with life in many places, meaning it is subject to the comings and goings of marine organisms that call this environment their home. Benthic invertebrates may travel up and down through the top few centimetres of the seafloor, dragging sediment along with them in a mixing process known as bioturbation. It is important to consider bioturbation when analyzing paleoclimate reconstructions from sediment cores.



Core locations and corresponding $\delta^{13}C$ time-series records of foraminifera from the NW Atlantic shelf region over the period of 1500-2005 AD. The smooth black line represents the average of all foraminifera $\delta^{13}C$ records and the smooth red line represents the $\delta^{13}C$ of atmospheric CO_2.

This mixing could dampen the trend of a climate signal recorded in the sediments, or perhaps add a bit more error to age estimates. Understanding the role of bioturbation in the observed Suess effect lag in my data is the next step I will be taking in this project. I am hoping that mathematical models may help in answering this question, as we can simulate how varying degrees of mixing would impact the oceanic $\delta^{13}C$ trend recorded in the sediments.

In conclusion

My master's thesis presented the first long-term time series of $\delta^{13}C$ for the Northwest Atlantic Ocean. I found that despite the five sediment cores being collected from very different ocean settings, the Suess effect is evident throughout the entire region. A few open questions remain, but my research thus far has demonstrated that fossil fuel-sourced CO_2 is making its way into the ocean and contributing to the risk of ocean acidification.

The outcome of my research adds to the growing collection of evidence that human activity is perturbing the Earth's natural climate cycles. Without mitigation, the threat of ocean acidification will continue to increase, and with it will come impacts on marine ecosystems and global economies. ■

This research was funded by the Natural Sciences and Engineering Research Council (NSERC), Environment and Climate Change Canada, Clean Nova Scotia, and the Canadian Meteorological and Oceanographic Society (CMOS).

Stefanie Mellon

Fascinated by history's tendency to repeat itself, Stef knew she wanted to study the past and the clues it left behind - in hopes of better understanding the future. She started off her science career in Dalhousie's Intergrated Science Program, which fostered her love for tackling the questions of nature from a holistic approach. Choosing to focus in paleoceanography was a natural next choice, as it combines big picture, long-term thinking with her love for understanding the Earth's dynamic environment. She double majored in Environmental Science and Ocean Science before continuing on to an MSc in Oceanography with Dr. Markus Kienast. After graduating, she moved to Victoria, BC in search of wind, waves, giant trees, and new experiences. When she is not at the computer interpreting paleoclimate data, you can find her kitesurfing at the beach, camping in the woods, or enjoying a beer with friends.

The Vehicle of the Future, 30 Years Ago

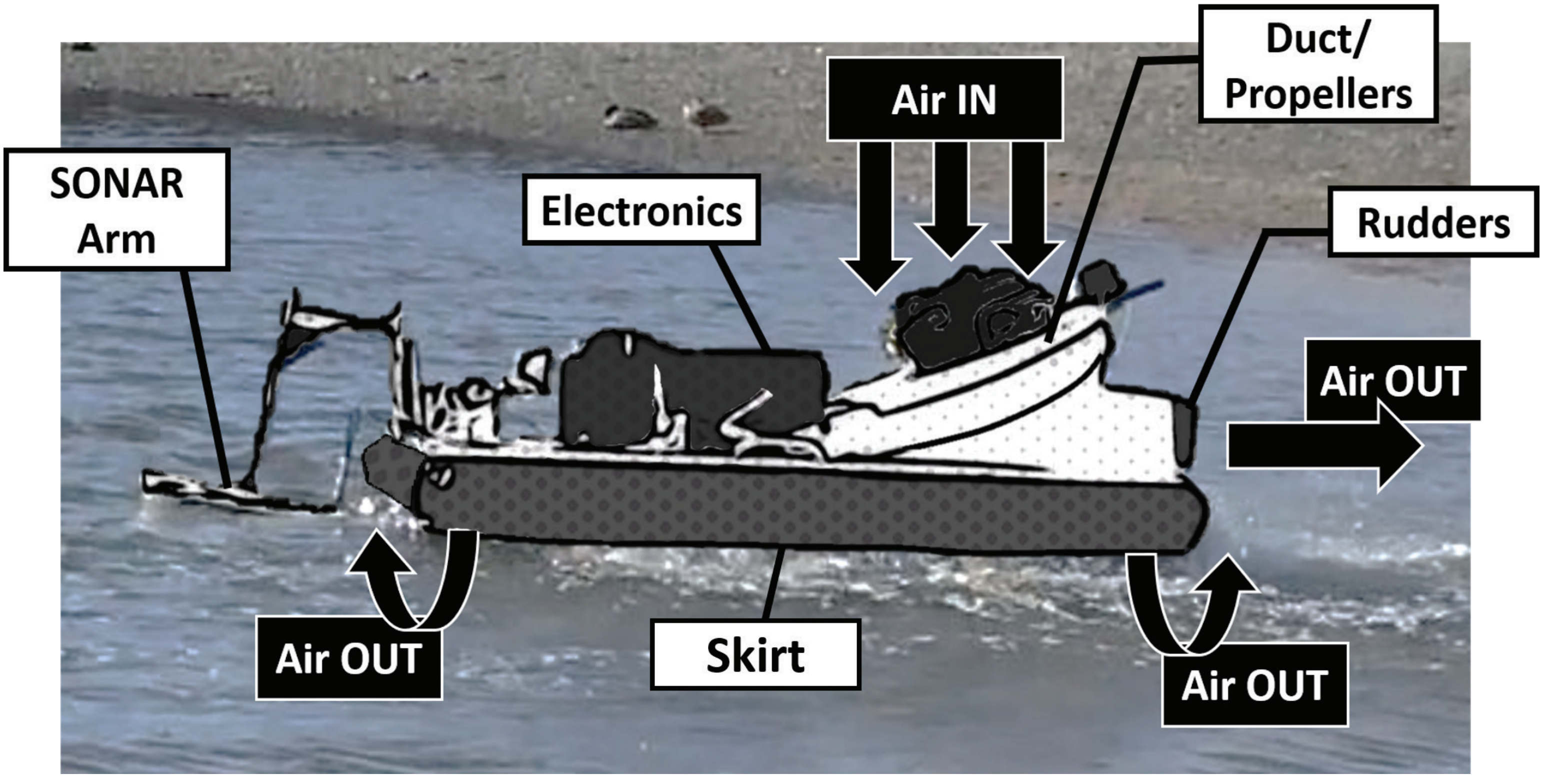
Using an autonomous hovercraft to create seafloor maps in very shallow water

Meghan Troup

Meghan and the hovercraft, preparing for a winter test flight in Halifax's Northwest Arm.
Photo: Dr. David Barclay.

Honestly, I never would have thought about developing a hovercraft to create maps of the seafloor, but when the idea was proposed to me, I jumped at the chance to be a part of this project. A few decades ago, hovercrafts were thought to be the vehicle of the future, used as alternatives to ferries or pleasure craft, but they have largely faded into obscurity in terms of commercial vehicles and transport. Nevertheless, they still have practical uses because of their maneuverability over multiple surfaces. These vehicles are used today by the military for heavy equipment transport across waters that may be difficult to maneuver by boat. In rare cases, they have been used as all-terrain platforms for scientific instruments as well. Hovercrafts have even been recently used in search and rescue operations, specifically in areas with dangerous flooding, because their movement is not limited by the flow of the water and they can move from land to water seamlessly.

The hovercraft's ability to fly over a variety of surfaces proves to be very advantageous when applied to common methods of mapping the seafloor in very shallow waters (less than 5 metres). Usual methods of mapping the seafloor include using optics or acoustics. Optical techniques include satellite



Schematic diagram of main hovercraft components. Air flow into and out of the hovercraft is depicted by black arrows. A few important components are also indicated.

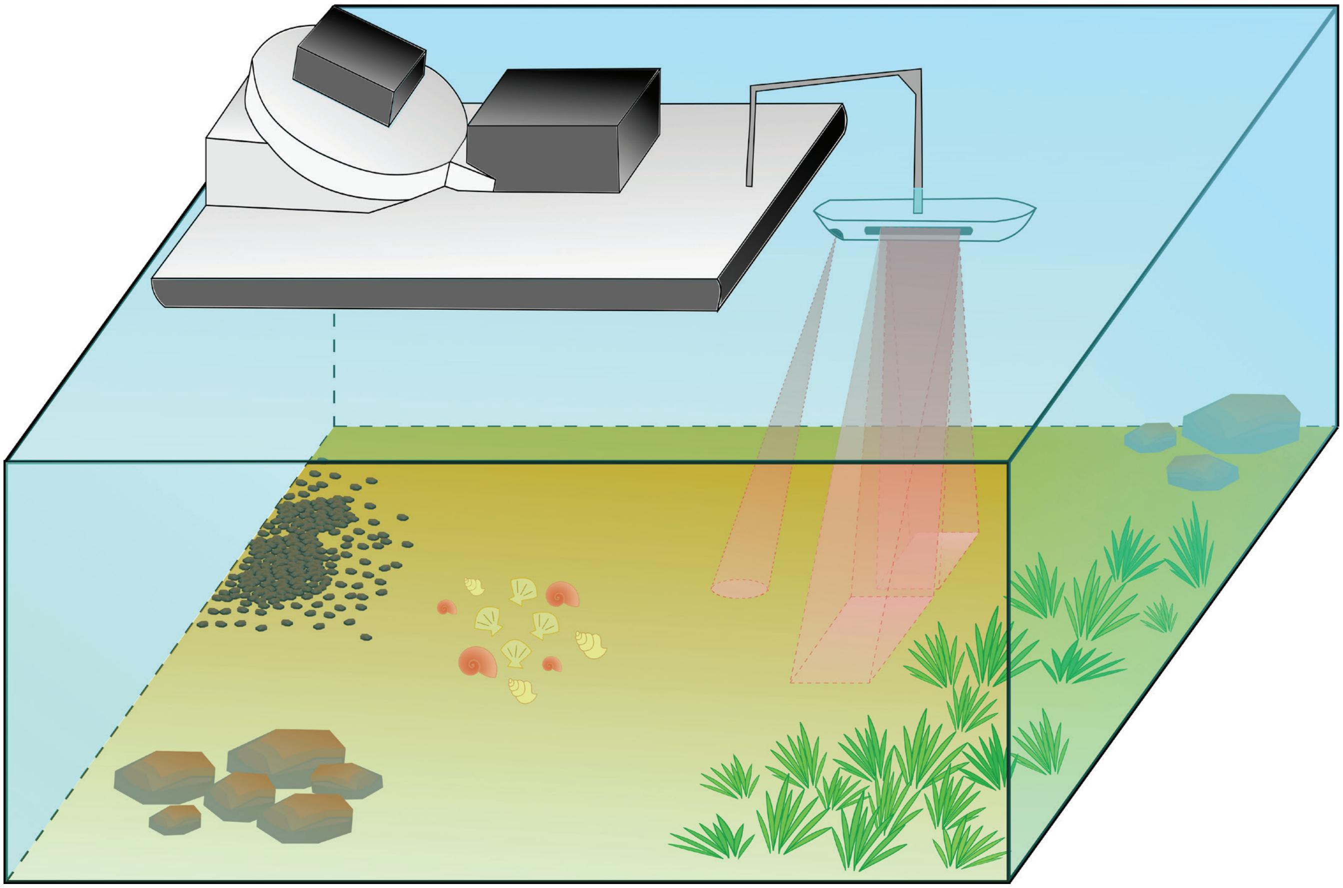
imagery, aerial photography, and bathymetric airborne LiDAR (pulses of light used to measure distance to the seafloor), but can also extend to underwater video, which is often used for manual surveys. Aerial methods are ideal for large-scale surveys because they cover large areas, but they are limited by the presence of clouds and the clarity of the water. Underwater video is likewise limited in effectiveness by the clarity of the water. Therefore, acoustic instruments are generally used for detailed seafloor mapping because they are more effective than optical instruments in cloudy water.

Coastal areas are highly trafficked by both commercial and non-commercial vessels, making accurate navigational and seafloor maps essential. However, the geometry of coastlines and seafloor topography can change over short time periods due to high-energy wave and current action. Maps of these areas are not only created for navigational purposes, but also to determine environmental details such as habitat distribution and sediment type. Large-scale acoustic studies, using instruments mounted to boats or autonomous underwater vehicles, are currently able to produce maps of coastal waters. However, many of these surveying methods are limited by depth. Consequently, maps for very shallow waters may not be detailed or complete. Due to their lack of depth limitation, hovercrafts offer an ideal solution for creating detailed maps of shallow coastal areas that are often overlooked.

The Development Part 1: Getting off the ground

Hovercrafts, no matter the size or shape, all have a few consistencies between them: a skirt and at least one air duct/fan system. Air is pushed through the duct by a fan and into the skirt, a fabric-enclosed air chamber on the bottom of the craft (shown in figure above). Once this skirt is inflated, small holes in the underside of the skirt allow a bit of air to escape, creating a cushion of air for the hovercraft to float upon – similar to a puck on an air hockey table. My hovercraft prototype has a few scientific additions to these basic elements, including two types of sonar instruments used to map the seafloor.

The sonar instruments used on the hovercraft include a single-beam echo sounder and side-scan sonar. A single-beam echo sounder is one of the simplest forms of sonar: the instrument emits a pulse of sound and records the time it takes for a reflection off the objects in its field of view (the seafloor, in this case) to return, taking into account certain factors such as sound speed in the water and water clarity. Side-scan sonars are mounted at an angle and emit fan-like pulses of sound to collect information over a large horizontal range. Other properties, such as sediment and habitat type, are determined by using the strength or intensity of this reflection. Using the received reflection, images of the seafloor can be created and fused together to make a complete and detailed map.



The hovercraft's side-scan and single beam sonars moving over various sediment types (including larger boulders, gravel, and sand), topography, seagrass, and organisms. Graphic: Jenna Hare

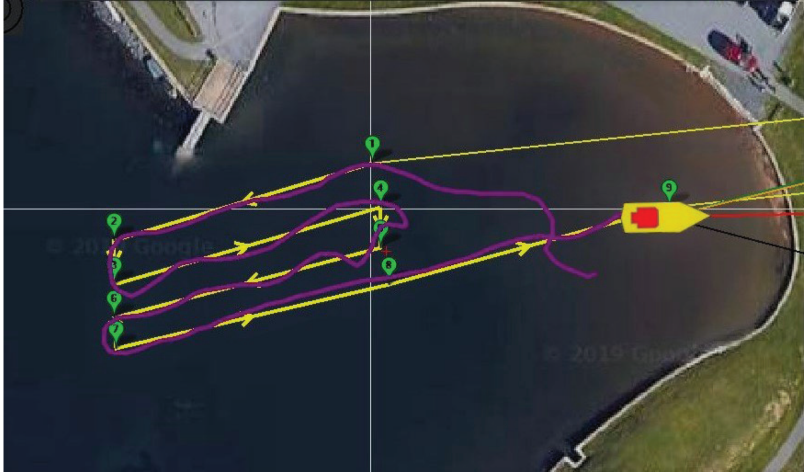
Building the hovercraft was largely a trial and error process. My team realized pretty early on that engines generally don't perform well when mounted at an angle. Our first engine orientation caused the engine oil to completely cover the spark plug, making it impossible for the engine to start. To fix this issue, we rotated the engine 180 degrees to stop the oil from reaching the spark plug but kept the angle the same. Tilting the engine also tilts the gas tank, which significantly decreases the distance traveled per tank of gas. Of course, we didn't realize that this could be a problem until the engine shut off while the hovercraft was in the middle of the Northwest Arm in Halifax. Thankfully, that's when we found out that the hovercraft floats! The angle of the engine still causes problems, but keeping it at that angle is necessary: angling the engine allows the fan to funnel air both into the skirt and out the back of the craft in order to propel it forward, meaning we only need one motor to fly our hovercraft.

The Development Part 2: Autonomy

Building a hovercraft and outfitting it with scientific instruments may be one battle in and of itself, but programming the hovercraft to move autonomously is another matter entirely. There is a cliché within the robotics and autonomous vehicle communities: autonomy does not mean intelligence. Robots are as smart or as stupid as the programs that control them. The hovercraft flies autonomously using an autopilot that is programmed with a pre-determined flight plan. The autopilot sends commands to the motors controlling steering and throttle to carry out this flight plan.

The autopilot can only reach the desired areas if the compass heading is accurate, therefore the compass must be calibrated. During an early autonomy test, my team realized that the hovercraft was having a bit of trouble finding the direction of the programmed destination. The hovercraft would veer off-course and would start spinning in fast, tight circles, not stopping until the vehicle ran into an obstacle. This behavior is termed the 'death spiral' by those in the robotics community (which is a pretty apt description for how the direction of the project felt to me at that point). After a lot of stressing and a bit of testing, we realized that our engine was interfering with the compass, causing the direction read by the compass to become increasingly inaccurate with time. Turns out, all we had to do was move the compass further from the engine to eliminate this interference. It was a ridiculously simple fix for such a disastrous problem.

I'm still working on the tuning process, where certain variables that control steering, speed, and navigation are changed within the autopilot programming. This process restricts the movement of the hovercraft's motors, creating a maximum speed and turning radius which allows for cleaner turns and straighter paths. Regardless of how well the hovercraft is tuned, however, there are some things that cannot be fixed completely. The hovercraft's single-fan system means that to decrease the speed, the lift (the amount of air funneled into the skirt) must also decrease, which lowers the effectiveness of the hovercraft when moving over a non-solid surface such as water. Moving forward, we've planned for a second hovercraft prototype with two motors that would isolate the steering and speed mechanisms in order to correct many of the issues with our first iteration.



A planned autonomous mission (shown by yellow lines and green waypoints) is compared to the actual path of the hovercraft (purple line).

What's the buzz?

There is a certain amount of satisfaction that comes from being able to create an autonomous hovercraft just to say we did it, but that's not the point of my project. Once the hovercraft is sufficiently autonomous and can effectively complete a planned mission, I'll be using it to survey eelgrass beds and create habitat maps. Eelgrass is the dominant species of seagrass in the northern hemisphere and is considered a species of interest in Canada, where it provides habitats and food for several important species of fish, marine birds, and other marine animals. Eelgrass is sensitive to changes in the environment, such as dissolved oxygen, salinity, temperature, and excess nutrients. It is also threatened by invasive species, such as the European green crab, and by eelgrass wasting disease, which caused massive mortality of the species in the 1990s.

Despite the importance of this species, up-to-date habitat maps for eelgrass beds are sorely lacking in Nova Scotia. A few habitat maps for regions along the Nova Scotian coastline are publicly available, but these maps lack detail and there are still areas that are unmapped and lack environmental data. Using the hovercraft, I can easily create updated maps throughout the year due to the vehicle's ease of deployment and ability to fly over multiple surfaces (including ice). Therefore, I can provide information about how these environments change seasonally or after storm events. These maps can provide vital information to scientists who study the ecological impacts of eelgrass on the surrounding ecosystem and to policy-makers who deal with protecting such ecosystems through marine protected areas.

My project may end with surveying eelgrass, but the hovercraft itself is a very versatile platform. My team plans to branch out and survey different environments such as rocky and sandy beaches or ecosystems with different seagrasses or algae. The sonar arm is removable, so it's also easy to replace the existing instruments with others (such as temperature and salinity sensors), making it possible to answer even more questions about coastal ecosystems.

Too long; didn't read:

Autonomous or unmanned vehicles are hardly new to the field of oceanography. The challenge is to keep creating innovative ways to study areas where even many remotely or autonomously-controlled vehicles cannot reach effectively. Engineering a hovercraft platform to efficiently collect data is a challenge that may never be fully completed, but with each new addition and alteration, we get closer to finding a simple and cost-effective way to create detailed maps in shallow coastal areas. Hovercrafts may have been the vehicle of the future 30 years ago, but they still have uses today. I've made it my job to figure out what else those uses could be. ■

This work is supported by Innovacorps and through the Natural Sciences and Engineering Research Council (NSERC) CREATE Grant through the Transatlantic Oceanographic School of Science and Technology (TOSST).

Meghan Troup

Despite growing up landlocked in Eastern USA, Meghan has always been drawn to the ocean. She decided to follow her passion as soon as possible and completed her BSc in Marine Science at a school as close to the ocean as she could find, settling in South Carolina. After four years, however, Meghan was sick of living in constant warmth and sunshine, so she decided to head north to discover what Canada had in store for her. Now, she's working on her PhD at Dalhousie University. When she's not taking the hovercraft out for a test run, Meghan likes to hike in remote areas, learn how to play obscure stringed instruments, and pet as many dogs as she can find along the way.

Lobster boats tied up at the dock in Blacks Harbour, New Brunswick.

How is a Lobster Like a Post Office?

Adventures in bay-scale lobster habitat mapping

Anne McKee

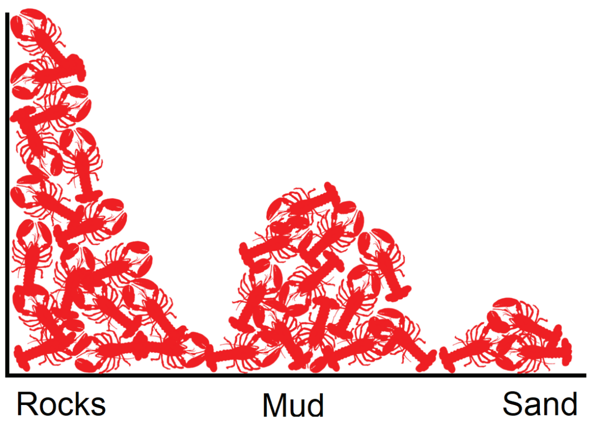
As anyone who's ever visited Nova Scotia will be able to tell you, the American lobster (Homarus americanus) is an important species in Atlantic Canada. Lobster fishing is still a way of life for much of the region, with the fishery bringing in hundreds of millions of dollars annually - about 90 000 tonnes of lobster. However, lobster fishing is not the only activity to take up space on the coastline: aquaculture, shipping, transportation, natural resource extraction, biological conservation, tourism, recreation, and other fisheries also vie for the limited space. Unfortunately, these activities can conflict with each other, competing for the same location, space, water depth, shelter, etc.

Marine spatial planning is the process of organising marine activities into a spatial structure based on the biological, sociological, political, economic, and cultural concerns of the area. In much the same way that many governments practice land use planning to organise the placement and development of resources on land, marine spatial planning is used to optimise the distribution of coastal activities, to account for potential conflicts, and separate activities that may overlap. However, marine spatial planning requires detailed maps of the activities, which can be difficult to produce. In particular, lobster habitat, an important factor in the lobster fishery, has scarcely been mapped at the local scale at which many conflicts occur. My graduate work involved creating those missing maps for Liverpool Bay, Nova Scotia, so they could be included in the local marine spatial planning process.

What's in a map?

A map, plainly put, is a simplified spatial representation of reality. The word simplified implies a reduction in complexity, which in turn implies that there were choices made about which details to include in the final product. These choices are made by the mapmaker in order to fulfil the purpose of the map. For example, a map of the post offices within a city needs to include, at a minimum, the city streets and the post office locations, but further details such as median household income, walkability scores, and sun/shade metrics are superfluous to this particular map.

However, the choices of what information to include in a map, and at what level of detail, can be deceptively challenging. The required information may be sparse or difficult to collect, which creates problems in the management and interpretation of the data. What if we only had data on locations where post offices were commonly built in the previous century? What if our information on the layout of the city's streets had to be pulled from photos on social media? Then the simple post office map becomes far more difficult to create than expected. What is the best way to make it? How should the data be interpreted? These are the types of questions I tackled in making lobster habitat maps of Liverpool Bay.



Lobsters preferentially select their habitat based on substrate. Rocky environments are the favourite, as they provide natural hiding places to escape predators. If there are no rocks around, mud is the next best thing because the lobsters can hide in dug out burrows. Sand is the least preferred substrate since it is too loose to burrow in and provides no structure to hide behind.

Finding the layers

To create a habitat map, one needs two main types of data: observations of where the species lives, and environmental factors important for the species (for example, temperature, landscape structure, water quality). Given that lobsters live on the bottom of the ocean, getting location data for them can be troublesome. Instead, I used lobster traps as an indicator of where lobsters could be found. In Atlantic Canada, lobster fishers tend to place traps in the same locations year after year, usually in historic spots where good catches are common. We can therefore assume that lobsters are present in the same locations as traps, since they have been so regularly in the past. For the environmental factors, I relied on the structure of the seafloor. Lobsters choose where to live based on the substrate; they prefer cobbles and rocks to gravel, prefer gravel to mud, and prefer mud to sand. The simplicity of this relationship is its strength, and I used it to assess likely habitat.

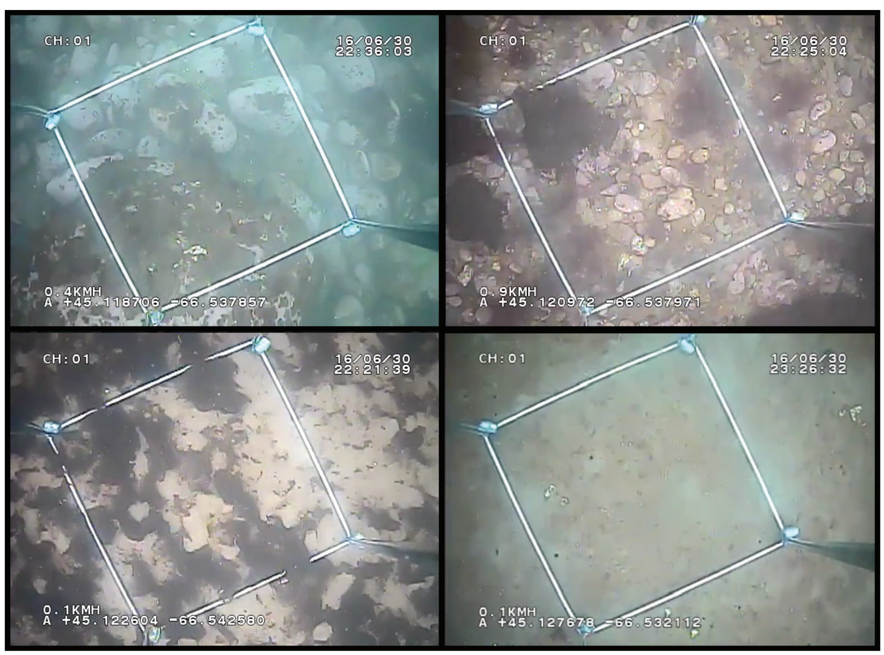
To “see” the seafloor of Liverpool Bay, I used an echosounder. The echo data can tell us whether the seafloor is hard, soft, rough, or smooth, which I then translated into rock, gravel, mud, or sand. However, when designing the survey to collect the data, there was one question to which I could not find an answer: how far apart should the data be collected? The distances between the data points affect the interpolation and therefore the outcome of the map. Despite this, I found no guidance on what distances to use in my design since there are no standards for this application. In fact, many seafloor mapping studies don’t even acknowledge this important issue, and instead simply state that the area was surveyed without sharing the particulars of how.

To deal with this unknown, I chose to compare the effects of different sampling distances. I made one map with data collected every 2.5 metres on transects 100 metres apart, while the other map showed data collected every 10 metres on transects 50 metres apart.

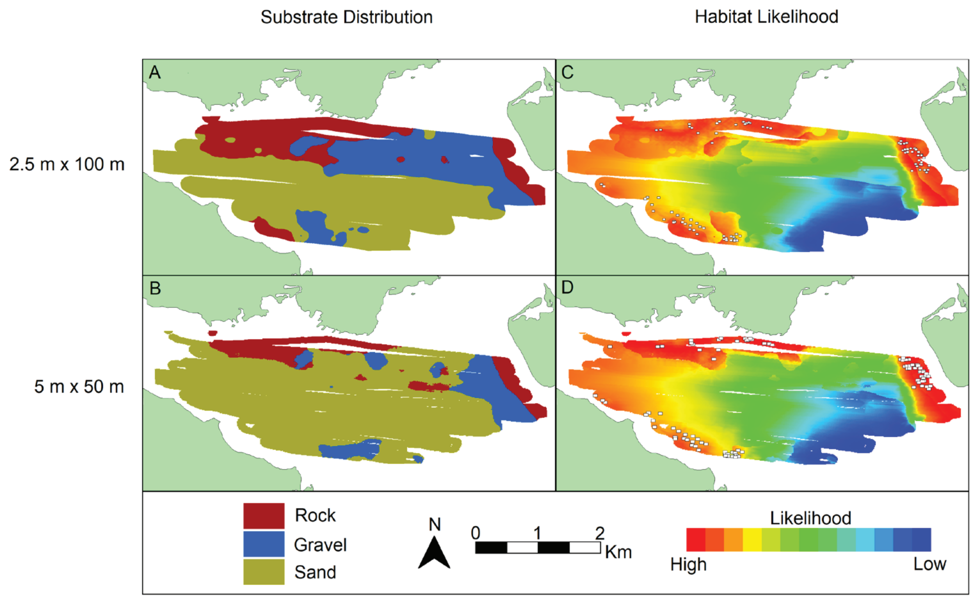
Same data, different results

Considering these substrate maps were made with the same data from the same location, they showed surprisingly different layouts of the seafloor - what was sand in one map was rock or gravel in the other, or vice versa. Which one was more accurate? According to my calculations, neither. The two maps were approximately equal to each other in accuracy, but in different ways. One was better at predicting the presence of rock and gravel, but tended to underestimate the amount of sand; the other predicted sand correctly, but often to the detriment of rock and gravel.

This difference can also be seen in the habitat maps, which I made by combining the substrate maps with the lobster trap data. The two habitat maps, identical in makeup except for the substrate data, show different likelihoods of finding lobsters



An underwater video camera was used to help translate the echosounder data into substrate types. The characteristics in the data were related to the substrate type seen in the video at the same point. Starting in the upper left and going clockwise, we can see: boulders, cobbles/ gravel, mud, and sand (with seaweed debris).



The substrate distribution in Map A predicts gravel and rock in places that are predicted to be sand in Map B, but the only difference in the creation of these maps is the density of the data collection. When these substrate maps were transformed into habitat maps (C & D), the differences are less clear but still visible.

in the bay. While the maps appear quite similar at first glance, the values associated with the colours are different. The habitat map made from the data that over-estimated rock and gravel (a lobster's preferred habitat) predicted a high chance of finding a lobster in the bay, whereas the habitat map that over-estimated sand, which lobsters dislike, shows a lower chance of finding lobster in the same bay. The maps find high and low lobster presence likelihoods in similar areas (for example, you'll be more likely to find a lobster near the shore than the mouth of the bay), but the strength of those likelihoods are quite different between maps.

Final thoughts

What does this mean for the interpretation and use of the maps? Which is the better one to use? Well, that depends on the purpose of the map. These habitat maps are meant to be used in marine spatial planning to help structure the use of the coast. However, the decision of which version of the habitat map to use could be based on the intent behind the planning. If the plan-makers had a risk-averse or conservative lean to their plan, or if the plan was being designed to deliberately discourage non-lobster-fishing activities, the plan-makers might decide to use the map that over-predicts lobster habitat. On the other hand, if the plan-makers were more accepting of risks or if the plan was designed to encourage non-lobster-fishing activities, the plan-makers might choose the map which shows far less potential lobster habitat. Since my work shows that there is little difference in accuracy between the maps, both choices would be valid and equally applicable. This means that the choice made may be due to the purpose behind the planning, some factor that is external to the creation of the map itself.

So the next time you see a map or a graph or a model, it might be beneficial to take a moment and think about the purpose behind it. What data could have been left out for the sake of simplification? What complications could have come from the data themselves? How might the data have been explained differently? These sorts of questions aren't meant to throw doubt onto the information being presented – after all, it's not unusual for science to have these little difficulties. Instead, I hope they remind us that data require interpretation and interpretation requires judgement. In much the same way that using imperfect data to make a map of local post offices would require some judgement in development, a habitat map designed for marine spatial planning will have had many decisions made about it along the way. The rationale behind those decisions is something that may be important for the reader to consider.■

This research was funded by the Natural Sciences and Engineering Research Council (NSERC) and Cooke Aquaculture.

Anne McKee

Growing up in a Nova Scotian lobster fishing village, Anne discovered her love of lobsters at a young age. Her interests in ecology and mapping led her to earn a bachelor's degree in Environmental Science from the University of Guelph. Anne then joined the Department of Oceanography at Dalhousie University and combined all three of her favourite topics in her master's degree, which she successfully completed in the summer of 2018.

Our Mobile Coast

Quantifying historic erosion in the Minas Basin using UAV-Based Photogrammetry

Ian Hay

Fifty metres above me, the bee-like hum of the drone's propellers sing out, louder then softer as the small white craft stabilizes itself against puffs of wind blowing in off the water. In my hands, the controller display shows red – deep orange red – the red of the mud here, of the stone, of the water. Massive cliffs rise up from seemingly endless mudflats, their sandstone walls calving off in house-size blocks like ice from glaciers. Above the sandstone lies a thick layer of till, scraped from the mountains to the north by the last glacier. Through this mixed layer of mud, sand and cobblestones run rivulets and miniature canyons, carved by rainfall and spring snowmelt. Above it all, a thin layer of topsoil supports an outstanding example of Acadian mixed forest, with spruce and birch occasionally losing their footing near the edge and tumbling to the beach below.

I'm here on the north shore of the Minas Basin to study the ongoing erosion of these sandstone giants: when their walls fail, how they fail and why. Using a combination of sophisticated digital surveying software and simple observations, I hope to create a link between what happens to these cliffs on an annual basis to historic erosion rates, observed from air photos dating back to the early twentieth century.

A long history of retreat

The farms and old homes that line the north shore of the Minas Basin are set back from the coast, their fields crawling up the slopes of the Cobequid hills. The people who settled here must have quickly realized the speed with which the coast retreated, and established their farms and buildings far from the cliff edge accordingly (those who didn't have long since fallen into the sea). In a few places, especially near the mouths of rivers, low fields are penned in by low earthen mounds – dykes – which keep high tides out of the cropland. These dykes are a lasting example of the Acadian farming influence in this area, where rich soils near the water's edge were reclaimed from the sea for agriculture by extensive systems of dykes and one-way valves, or aboiteau, which have now become an integral part of the built environment. Without constant upkeep, these structures would soon befall the same fate as the natural cliffs in this area, and the fields would rapidly return to their natural state of marsh and mudflats.

Looking out from 50 metres above the seafloor, expansive mudflats dyed red by high iron content sandstones which make up the cliffs at Thomas' Cove. Large blocks at the base of the cliffs indicate periodic large failure events, which may coincide with seasonal weather patterns or storm events.

Locator map of the north shore of the Minas Basin with a star showing the study site at Thomas' Cove in Economy, Nova Scotia.

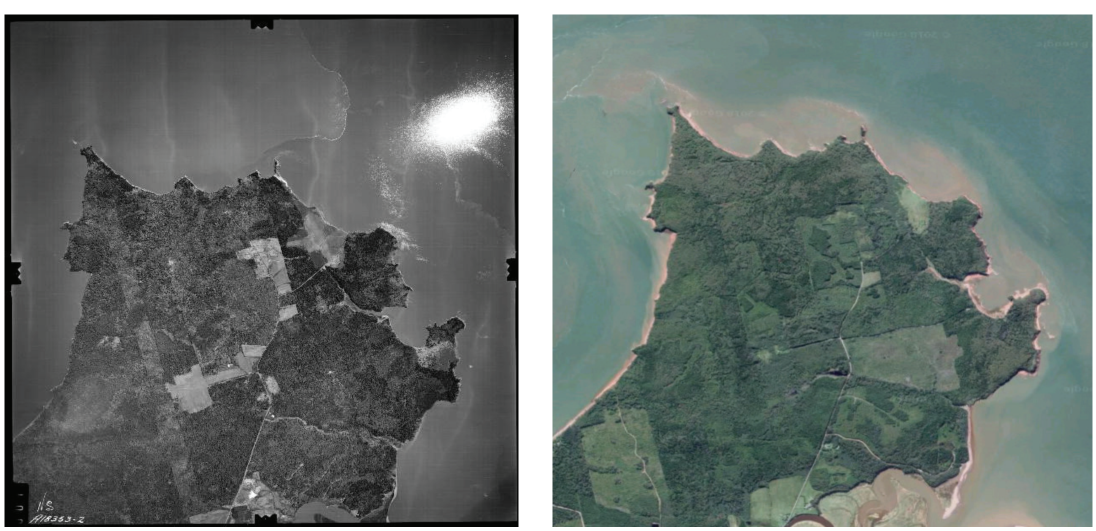
With the exception of sparse dykelands, the attitude toward coastal erosion is somewhat different here from coastal areas elsewhere on Earth; people here have traditionally accommodated the massive tides and retreating shorelines, instead of attempting to fight back with various engineering solutions. There are very few people who live along this coast, though at one time the hills and harbours were filled with loggers, millworkers and shipwrights who established the many small communities that dot the shore from Masstown to Parrsboro. Today, fewer than 400 people live along this corridor year-round, the highest concentration being in Parrsboro, which also receives a large influx of summer residents and vacationers each year. As such, there are still large stretches of the coastline that have been left untouched, allowed to continue much in the way they always have, their interaction with the tides, the wind and the elements unfettered by human intervention. Thomas' Cove Coastal Reserve is one such place, and the site for my study.

My research

Erosion is an invisible continuum. To understand erosion today, we must know what it has been historically. This is not always easy, considering the evidence often relies on the observations of earlier generations. At Thomas' Cove, we are fortunate to have nearly 80 years of decadal aerial imagery covering the cliffs of interest. Using geospatial software, I have oriented each of these photos to one another and extracted the shoreline positions. From the shoreline positions, I can calculate rates of retreat between photo dates and across all 80 years. Using this technique, we found that decadal retreat rates are roughly 0.4 metres per year, with slightly higher values in the 1960s.

Annual retreat measures by drone

I am interested in the mechanisms causing erosion at Thomas' Cove, and hope that observing the cliffs over a few seasons will tell me more. Collecting detailed structural information with precision has long been a time-consuming task requiring large teams of skilled surveyors and technicians. Aerial photographs taken from planes and helicopters, while extremely helpful in determining long-term change, are prohibitively ex-



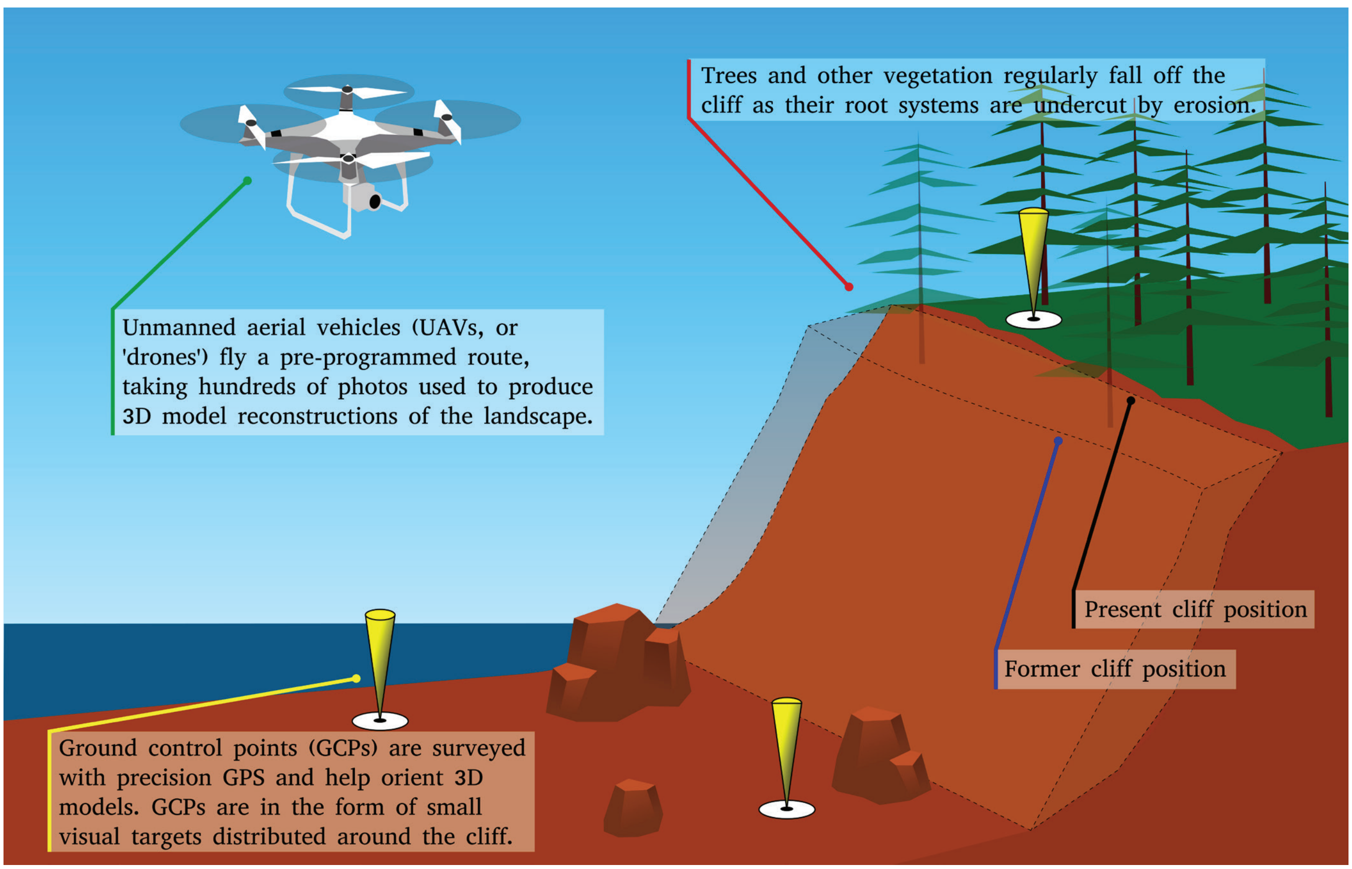
Aerial photos of Economy Point. On the left, an air photo from 1964, and a satellite image from 2018 on the right. Historic aerial photos helped to calculate decadal retreat rates at Thomas' Cove since 1938.

pensive for most studies. The recent development of unmanned aerial vehicle (UAV) or drone technology has minimized these limitations.

I hope to demonstrate that short-term studies using drones are a viable technique for monitoring shoreline change in high-energy, rapidly eroding environments in the Minas Basin and elsewhere. Drone surveys are carried out using an automatic flight controller, for which several flights have been programmed to achieve optimal overlap between images. Reference targets called ground control points (GCPs) are distributed throughout the study area and surveyed using a precision GPS unit. Overlapping images in concert with GCPs can be used to reconstruct the coastline in the form of a 3-D model using a method called structure-from-motion photogrammetry (SFM). SFM is essentially running thousands of trigonometric calculations on points that the software recognizes within photos. From those calculations, the software reconstructs a 3-D model of the environment.

Imagine you are looking straight down on a bottle of hot sauce; if this is all the available information you have, the only thing you can say about the object before you is that it is a circle. Now, moving to the side of the bottle by one metre, it becomes apparent that the bottle does in fact have a vertical dimension. By knowing where you are at a given moment, and where you came from, you begin to get an idea of the bottle's proportions. The software we use does the exact same thing, but with many more points. Not only is it cheaper to collect drone imagery, there is also far less gear, meaning that remote or challenging environments can be surveyed with the same precision as with other, more costly surveying methods.

Similar technologies such as terrestrial laser scanners, or other applications of light detection and ranging (LiDAR), are generally used to measure environments from a single orientation (for example, from the side or above). What is so cool about structure-from-motion is that it works from all orientations, in fact it excels in being used that way. Because of this quality, the models we produce can be used to measure horizontal



UAV-based structure-from-motion (SFM) photogrammetry was used to construct 3-D models of sections of retreating cliffed coastline. Graphic: Tristan Guest.

retreat just like we can from the air photos, and the surface volume change over the entire cliff face. This second characteristic may allow us to figure out how much material is actually entering the Minas Basin from these cliffs, which may have implications for technologies such as tidal hydroelectricity. Moreover, this multi-view approach will help us characterize the ways in which erosion occurs, what parts of the cliff are most susceptible to failure, and how this changes over time.

Tidal model comparison to historic water levels at St. John

In any coastal environment, storms exacerbate erosion. The Minas Basin is situated at the upper reaches of the Bay of Fundy, which is in resonance with the larger tidal system in the Northwest Atlantic. This resonance, due in large part to the length and depth of the Basin, produces the highest tides in the world. When storms blowing out of the southwest arise, more water is pushed into the basin, causing water levels to rise even more. The cliffs at Thomas' Cove are oriented such that they will take the brunt of any storm rolling up the coast.

For this reason, we are investigating the relationships between recorded storms and high water by comparing the recorded water levels at Saint John, New Brunswick to a hindcasted model prediction. The model calculates the ideal tide that would occur if only celestial bodies and the geometry of the coastline were acting on the ocean. When a storm arises, the water level at the Saint John tide gauge will read higher than the model-predicted level. Luckily, the model can predict both what the tides will be and what they were. Deviations between the tide gauge readings and model prediction should indicate periods of storminess, and thus increased risk of erosion.

Conclusions

The cliffs along the north shore of the Minas Basin are in constant motion, continually losing ground to the tides that lap their base. For now, the rate of erosion appears to be similar to what it has been for the last century, calving away about half a metre every year. However, changing oceanographic and seasonal conditions could threaten this coastline in the future, leading to longer and more intense freeze-thaw periods, bigger storms, and wetter springs, all of which conspire against these ruddy giants. Although 80% of the global coastline is comprised of cliffs, only a small fraction experiences large tides like those seen here. For this reason alone, it is important to study the dynamics of erosion in a macrotidal (greater than four metre tidal range) environment, and to fill a knowledge gap in an area that has traditionally proved too difficult to conduct research in conventional ways.

In the future, I hope to expand this method to other macrotidal cliffed coastlines and to produce a more comprehensive model of the intertidal zone, from lowest low water to the cliffs' top edge. This may show that cliff erosion is an important point source of sediment and thereby influences in-stream sediment dynamics in the Minas Basin. The Minas Basin is a big environment which holds many mysteries; I hope my work will help uncover a few. ■

This research was funded by a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery grant.

Ian Hay

Growing up in Boston, Massachusetts, a city whose present land area is largely filled-in harbour, marsh and millponds, Ian became normalized to radically moving shorelines (albeit at the hands of humans). After graduating from the University of Maine in Orono with an undergraduate degree in physical marine sciences, Ian looked beyond the curve of the Earth to Nova Scotia to pursue a master's degree with Dr. Paul Hill. Here he plays in the Fundy mud and uses drones to measure firsthand a coastline that moves entirely on its own accord. Having a fascination in the built environment and maps, Ian is particularly interested in the way coastal landscapes influence the people who have settled along their shores, and what adaptations these societies have made in the past and will be forced to make in the future. When not in his office or coercing fellow graduate students into boat purchases, Ian can be found sailing, kayaking, skateboarding and generally messing about in greater metropolitan Shad Bay.

Harnessing the Ocean's Recycling Depot

Using phytoplankton mass cultures to remediate wastewater streams and produce valuable products in the process

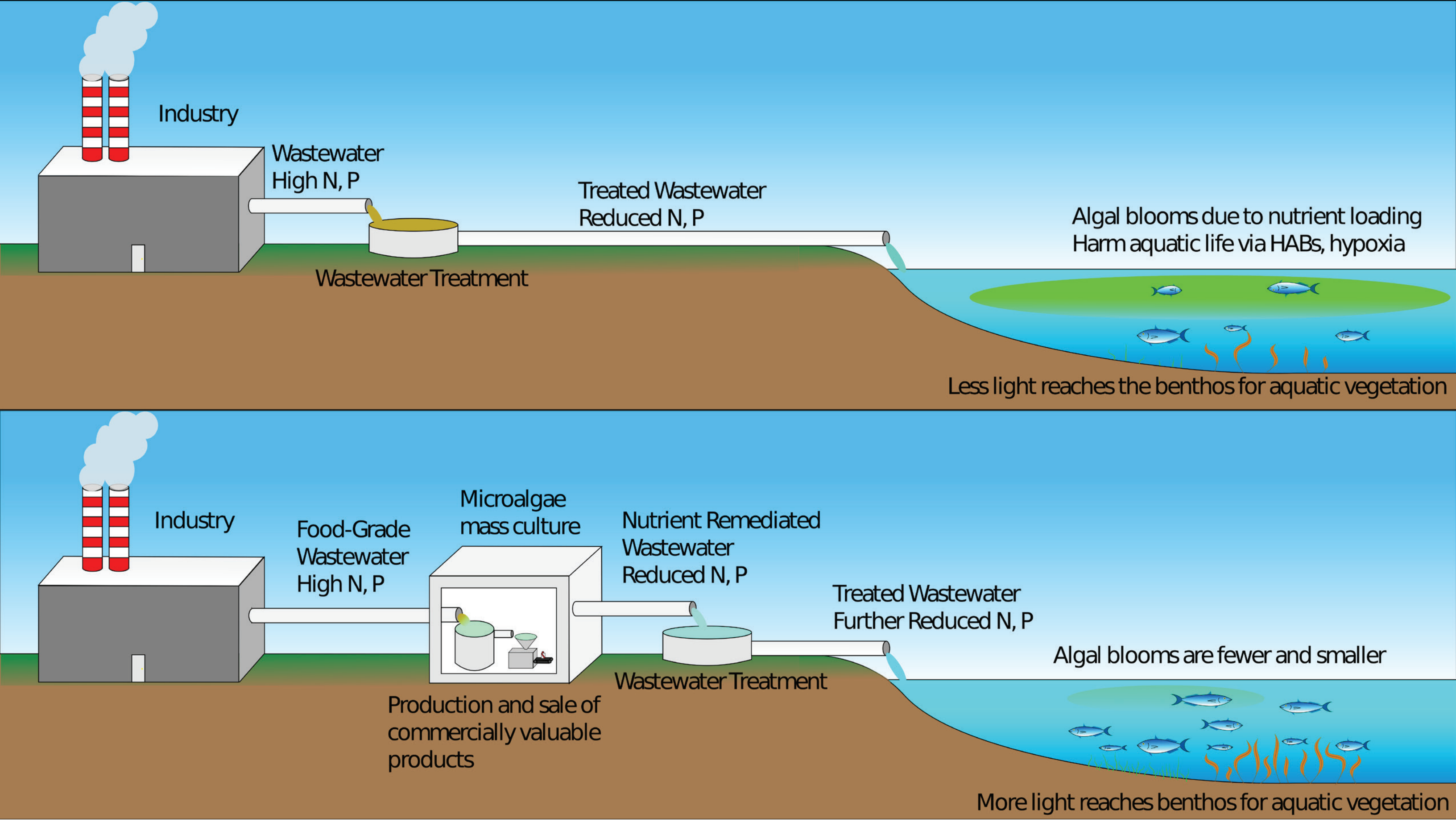
Rhyl Frith, Rory Macklin, Nan Chen, and Reid Steele

Have you ever sat by the shore on a sunny summer afternoon and been struck by how alive the ocean can be? Perhaps you looked out over the horizon and saw a flock of seabirds dipping and diving gracefully into the waves in search of their next meal, or you gazed down into the still waters below a wharf at high tide and noticed schools of minnows flashing their silvery sides this way and that. The ocean teems with life, and it's all thanks to microscopic photosynthetic organisms known as phytoplankton.

Phytoplankton contribute to about half of global primary production and occupy the base of the marine food web. Like land plants, phytoplankton need nutrients to grow. However, unlike most land plants, many phytoplankton are mixotrophic, meaning that they can acquire energy through both photosynthesis and consumption of organic matter. The nutrients that phytoplankton need are supplied to the ocean via rivers, groundwater and atmospheric deposition. Excessive nutrient input (better known as eutrophication) from agricultural runoff and wastewaters may lead to an overgrowth (bloom) of phytoplankton, which strips oxygen from the water column and prevents sunlight from reaching other plants in deeper waters. These blooms can even be toxic (known as harmful algal blooms or HABs), which can lead to massive die-offs of fish and invertebrates. Thus, the treatment and minimization of wastewater streams play a major role in preventing eutrophication and harmful algal blooms in coastal waters.

One method of minimizing wastewater streams is by repurposing potentially useful products, notably nutrients, that would otherwise be discarded. Many wastewater streams are contaminated with endocrine disruptors, heavy metals and pharmaceutical products, which makes intercepting their nutrients for the purpose of eventual human consumption unviable. However, food-grade waste streams - resulting from products meant for direct human consumption - are ideal for extracting high quality nutrients to feed phytoplankton cultures in the food sector. Our research goal is to devise an inexpensive method

Stock cultures of various strains of microalgae (A) and liquid waste used for waste-amendment (B)



Summary of outcomes of interest resulting from waste amendment. Graphic: Reid Steele.

of repurposing nutrients from food-grade waste streams to use in the commercial growth of phytoplankton. As a result, we hope to minimize the contribution of these waste streams to eutrophication, while also improving growth and cutting costs of commercial phytoplankton mass-culture.

Why culture phytoplankton?

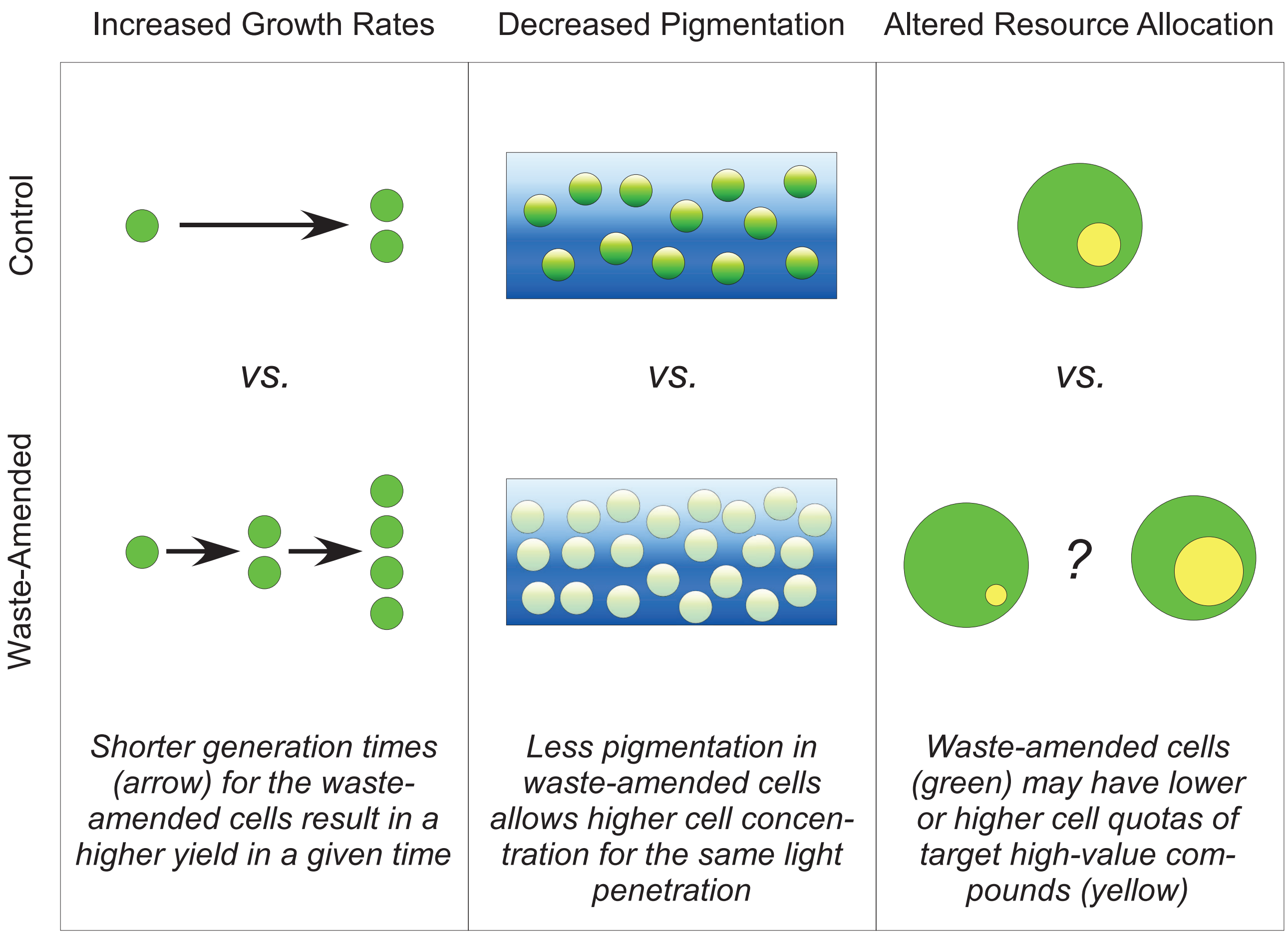
Phytoplankton in the ocean are very dilute, but culturing them on an industrial scale allows biomass to be concentrated enough to harvest for commercially valuable compounds or to be used as aquaculture feeds. One example of a valuable compound produced by phytoplankton is the pigment astaxanthin, which is a fundamental component of salmonid feed. Astaxanthin is responsible for the pink colour of salmon flesh, which is highly correlated with its market value. As for direct human consumption, many phytoplankton are excellent sources of omega-3 fatty acids, the antioxidant carotenoids β-carotene and lutein, plant proteins, and polysaccharides that may be used in cosmetics, food supplements, and even pharmaceuticals.

Phytoplankton are essential in many aquaculture operations as a live feed for larval crustaceans, some larval fishes, and all life stages for bivalves. Culturing phytoplankton provides a constant supply of food for these species, which decreases production time and increases product quality. Nutrient-rich, food-grade wastes can be used as a nutrient supplement for culturing phytoplankton, which in turn can be used as a live feed or a high-quality component of pelleted feed. This type of multi-trophic production cycle would integrate wastewater remediation into aquaculture, intercepting and recycling nutrients and directing them away from natural ecosystems. From the commercial perspective, this cycle would also potentially cut operating costs and increase growth efficiency for both the phytoplankton and aquaculture species in the process.

Since many phytoplankton are mixotrophic, we focused on testing the effects of a food-grade liquid waste on the growth rate and biomass yield of a wide taxonomic range of phytoplankton. The food-grade waste we used in this study contained much higher concentrations of nitrogen and phosphorous than would typically be found in growth media. If the phytoplankton can metabolize it, the waste could be used in place of the usual media constituents, reducing costs. The waste also has a very high concentration of dissolved organic carbon, which might fuel increased growth rates by providing directly usable energy to the cells. Demonstrating that the phytoplankton are able to use the nutrients or the organic carbon in the waste would be the first step towards coupling waste-water remediation to commercial production of phytoplankton biomass or bio-products.

Testing the idea

We selected ten species of phytoplankton for testing. All were robust, easy to culture, and commonly used as feeds in aquaculture. The test species were highly diverse, coming from four divisions (phyla). We cultured these at different



Comparison of standard (top) and microalgae culture nutrient-remediated (bottom) food-grade wastewater disposal. Graphic: Dr. Hugh MacIntyre.

light intensities and with different additions of the food-grade waste to test for environmental and/or concentration-dependent effects. The cultures were grown in batch mode, meaning we did not give them additional nutritive media, nor was the old medium removed, and their growth was tracked until they ran out of nutrients and stopped growing. We monitored the cultures daily by using chlorophyll fluorescence techniques that give proxies of abundance and physiological status. Once the cultures stopped growing, we harvested them and analyzed for cell abundance, size, composition, chlorophyll concentration, and chlorophyll per phytoplankton cell.

The results were concerning at first. Growth curves for cultures grown with a 5% addition of the food-grade waste showed a complete arrest of growth in all but one species. This suggested that the compound could be toxic, which would force us back to the drawing board to find another waste source. In response, we tried a much lower waste addition of 0.5%. Fortunately, the lower addition yielded different outcomes depending on the species, ranging from a complete arrest of growth, to no apparent effect, to increased growth rates (see figure above, left panel). We also found that the species which grew well in our experimental treatment contained far less chlorophyll per cell, meaning that the cells absorbed less light and thus performed less photosynthesis for energy (see figure above, middle panel). Having less chlorophyll per cell is a good thing in mass culture because less pigmented cells allow more light to reach the cells deeper within the culture, which reduces self-shading. Additionally, our monitoring method tracks chlorophyll as a way to estimate the amount of phytoplankton in the culture, meaning that because our waste-amended cells had less pigment in them, we saw a smaller increase in growth rate than was actually occurring. Another interesting result is that cells in the species which showed improved growth had a comparable biomass to the control (unamended) cultures, but were larger and fewer. Larger cells are easier to harvest in an industrial setting, so this is a positive result.

Where do we go from here?

In these experiments, we were able to show that a food-grade waste with high nutrient and organic content could stimulate phytoplankton growth rates, increase the number of cells that can fit in a culture at the same light level, and reduce energy costs by growing phytoplankton at a comparable rate at lower light levels. Applying these results to an industrial setting has the potential to increase production and lower costs. In the context of commercial production, we need to ensure that whatever product we are trying to produce using the phytoplankton culture is generated at comparable or higher rates in waste-amended cultures. In the context of aquaculture, we need to ensure that waste-amended phytoplankton cultures have comparable palatability and appropriate lipid and amino acid signatures to counterparts grown on standard media.

Every day, an incomprehensible amount of repurposable waste ends up in our environment. By applying this work on an industrial scale, some of this waste could be intercepted and reused to culture phytoplankton. This method has the potential to reduce the nutrient and energy requirements of existing phytoplankton culturing systems and produce high-value foodstuffs for human or animal consumption. In the process, we could reduce nutrient loading and the likelihood of its consequences; eutrophication, harmful algal blooms, and hypoxia. Though it has a long way to go, our research is a step in the right direction towards a more sustainable future.

This research was funded by a Natural Sciences and Engineering Research Council (NSERC) of Canada Discovery Grant (RGPIN-2018-06730) to Hugh MacIntyre, with additional funding from the Ocean Frontier Institute Seed Fund and the Nova Scotia Co-operative Education Incentive. Reid Steele and Rory Macklin were partially supported by Undergraduate Student Research Awards from NSERC.

Reid, Rhyl, Rory, and Nan are all former co-op students in Dr. Hugh MacIntyre's lab. The lab primarily studies industrial phytoplankton mass culture and is currently researching methods to improve mass culture efficiency.

Rhyl Frith

Rhyl Frith is a Marine Biology Co-op Honours student at Dalhousie University. Growing up around Nova Scotia has instilled a passionate love for the ocean in her. She chose to study marine biology so that she could contribute to ocean conservation, and her experiences with co-op placements and seaside courses have exposed her to numerous avenues for exploring ocean conservation, including phytoplankton research.

Rory Macklin

Rory Macklin is a Marine Biology Co-op student at Dalhousie University. Spending lots of time by the shore during his childhood in Cyprus, and later on Vancouver Island, British Columbia, instilled in him a passion for the sea. He is very interested in science communication and enjoys sharing his wildlife photography. He is glad for the opportunity to apply his interest in science communication through the writing of this article.

Nan Chen

Nan Chen grew up in Wuhan, China. Spending time watching The Blue Planet and visiting the shorelines with his parents enlivened his passion for discovering the sea. Following his passion, he chose to pursue an Honours Marine Biology degree at Dalhousie University, through which he came to realize that aquaculture is a needed solution to conserve the fragile aquatic ecosystem. Nan is looking forward to developing an honours project that connects phytoplankton and aquaculture.

Reid Steele

Reid Steele is a Marine Biology co-op student at Dalhousie University from Edmonton, Alberta. He developed an interest in fish, fisheries, and the water from summer trips to the lake with his grandfather, which led him to pursue a degree at Dalhousie. In his final work term as a research assistant for Dr. Hugh MacIntyre, he developed a strong interest in research. He is currently finishing his honours degree in marine biology with a minor in oceanography.

Thank You!

The contents of these pages represent countless hours of volunteered effort by a dedicated team of student authors and editors. All of those involved have my gratitude for their hard work and (no small amount of) patience over the past year. The unique perspectives offered by the authors combined with the keen eyes of the editors have once again resulted in a product we can be proud of.

It instills a great sense of confidence to have received such stalwart support from the Department of Oceanography, and from our generous sponsors, some of whom have contributed to the magazine since its inaugural issue in 2013. Thanks to Paul Hill, our department chair, for agreeing without hesitation to write the introductory letter to this issue – his third instalment!

I extend my sincere thanks the editors-in-chief of the past three issues: Franziska Broell, Justine McMillan, and Lorenza Raimondi. My life was made considerably easier by having a clear trail to follow – one already blazed by their hard work. Thanks to Jenna Hare for her willingness to engage in frequent discussions about the magazine, and for contributing graphic design work. Thanks, also, to our layout designer Tracey, for helping us transform our efforts into a document worth sharing.

Finally, a big thank you goes to the students of the Department of Oceanography. It is their collective excitement and commitment to an active student society that makes this endeavour possible and worthwhile.

Tristan Guest
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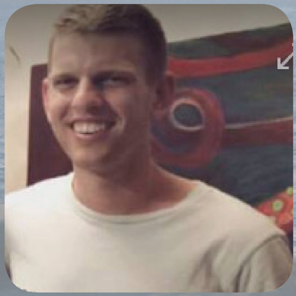

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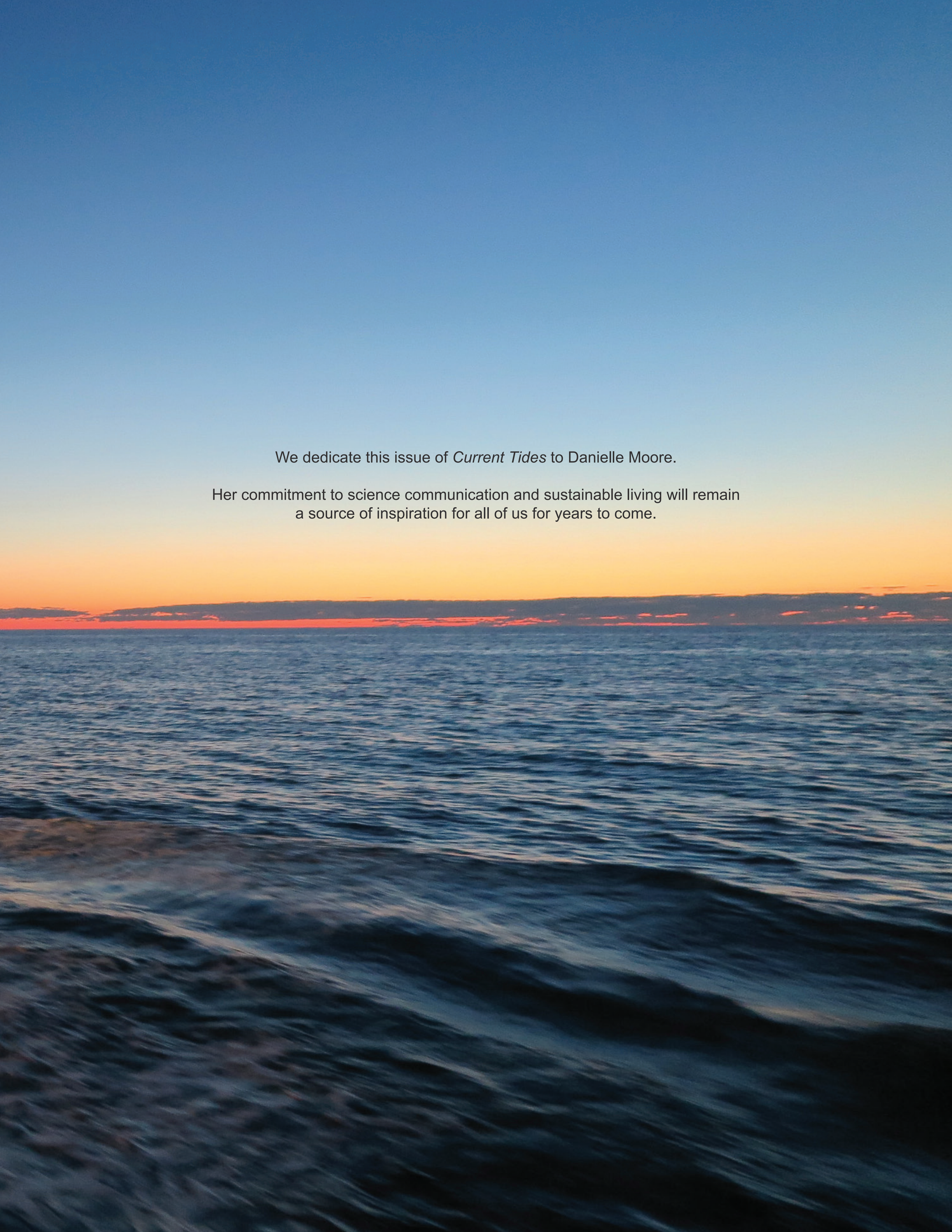

We dedicate this issue of *Current Tides* to Danielle Moore.

Her commitment to science communication and sustainable living will remain a source of inspiration for all of us for years to come.

Current Tides

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