Current Tides

Dalhousie Oceanography Research Magazine

Volume 2
2015
dal.ca/oceanography

Current Tides

All article photographs/figures were provided by authors unless credited otherwise.

Cover: Photo courtesy of David Barclay
Back: Photo courtesy of Mathieu Dever

Editor-in-Chief: Justine McMillan

Editors: Jean-Pierre Auclair, Jonathan Izett, Anne McKee, Andrea Moore, Lorenza Raimondi, Gennavieve Ruckdeschel, Krysten Rutherford

Financial Manager: Justine McMillan

Print Design: James Gaudet

Graphic Design: www.tandemhalifax.com

To send letters to the editor and/or receive the print publication, email justine.mcmillan@dal.ca or visit www.currenttides.ocean.dal.ca.

Department of Oceanography
Dalhousie University
1355 Oxford Street
Halifax, NS, CANADA, B3H 4R2

A Letter From the Chair

It is my distinct pleasure to recognise the graduate students from Dalhousie's Department of Oceanography for the initiative, intellect, and passion that they have shown in producing this edition of *Current Tides*.

The Department of Oceanography at Dalhousie is a flagship for oceanographic research, technology and education. The graduate students in the Department crew that ship, spending long hours troubleshooting equipment malfunctions, debugging computer code, trying to stay warm and dry, and generally having exciting and fun times studying our planet's watery realm. *Current Tides* is a celebration and recognition of the students' hard work, and it provides an accessible and attractive porthole through which the broader community can view the compelling research that drives the Department.

The research described in this issue for *Current Tides* is remarkable for its breadth. The students report on the challenges and potential for acoustic detection and identification of whales (Carolyn); on the use of models and autonomous glider observations to investigate the Nova Scotia Current (Mathieu); on dust fluxes through time to the warm blue waters of the equatorial Pacific (Diksha); and on how a small invasive colonial organism is affecting the viability of lush kelp beds fringing Nova Scotia's rocky shores (Danielle). We learn how acoustic technology developed at Dalhousie is producing new insights into the complicated flow of water over ripples, knowledge that is required to understand how sandy shores respond to and protect us from storm waves (Jenna); how oxygen isotopes in Halifax's Bedford Basin can be used to understand large-scale regional changes in freshwater inputs to the Arctic and Northwest Atlantic Oceans (Liz); how acoustics may be able to alert us to the presence of potentially damaging, submerged ice blocks in the vicinity of tidal power generators in the Bay of Fundy (Nick); and how crisp seafloor images help us to explore habitat and diversity in the deep Gulf of Maine (Myriam). I extend my sincere thanks to the Editor-in-Chief Justine McMillan, the editorial staff, and the print and graphic designer. *Current Tides*, quite simply, makes me proud of our students and their accomplishments.

Bravo Zulu!

Paul Hill, Chair of the Department of Oceanography

Contents

Having a Whale of a Time With Signal Distortion

Investigating the impacts of environment-dependent acoustic propagation on automated detection and classification of marine mammals

Carolyn Binder

Imagine standing in a large dark room where your only sense is sound. You're trying to talk to the girl across the room from you, but you can't see her and there's some construction noise coming from outside. Even when she listens carefully, she can hardly understand you because your voice has bounced off the walls, ceiling and the floor causing it to sound echoey. While we struggle to communicate in this type of environment, whales thrive! They spend most of their day below the ocean surface where it is dark and they must rely on sound to communicate with one another.

We, as scientists, have been trying to eavesdrop on whales for decades. We want to figure out the mysteries of the deep, and part of that is being able to tell when and where whales are present. But whales spend the majority of their time underwater so we can't see them once they dive beneath the surface. By listening to the whales instead, we can identify the species and gain insight into their behavioural patterns. This allows us to learn interesting things about their population sizes, migration patterns and responses to human activities.

The most convenient way of doing this is to use a hydrophone (essentially an underwater microphone) to monitor and record underwater sounds. Ideally, an automatic system would alert us when whale calls are present in these recordings, but computers struggle both to accurately detect a whale call (i.e., a vocalization) and to classify the species from the vocalization. Some of the difficulty is due to the "echoiness" of the received signal since the whale call gets distorted as the sound travels through the ocean. The environmental properties of the ocean (like temperature, salinity, bottom type, depth, and wave height) all affect the way in which sound travels, resulting in a signal at the hydrophone that is different from that emitted by the whale. This can make it difficult to identify the species from a whale call since the same vocalization may sound different when recorded in the Arctic than in the Bay of Fundy.

That's where my research fits in. Instead of using traditional classification methods, I'm working on a new type of technology that may be less influenced by the distortion of the sound signal. This system would be a great benefit because it would allow us to identify whales in a diverse range of ocean environments.

Listening to whales the standard way

In the scientific community the use of a hydrophone to monitor underwater sounds is referred to as "passive acoustic monitoring", or PAM. This method has been used since the late 1940s when scientists first realized that whales produce sounds underwater. PAM has been used to study whales in regions all over the world where the water properties are drastically different. For example PAM has been used: in the tropical waters of Hawaii to study humpback whale behaviour; in the temperate waters of the Bay of Fundy to detect the presence of

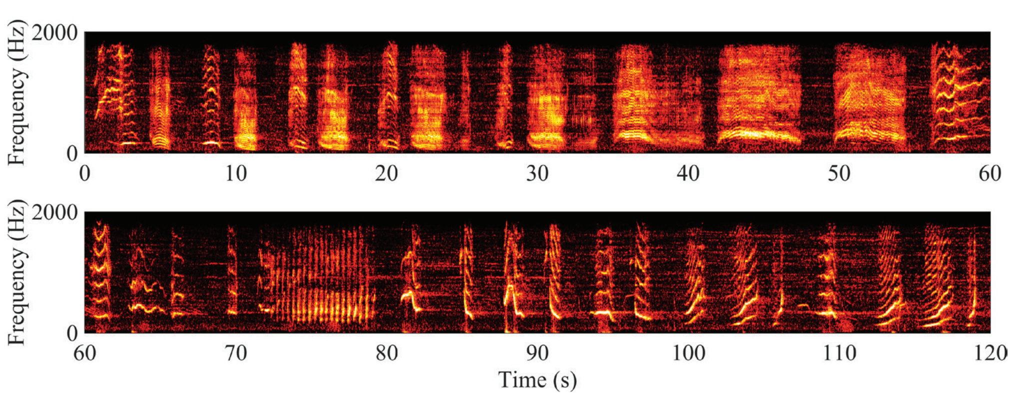


Figure 1. Example of a spectrogram of humpback whale song. Colours that are redder represent more intense sounds. The sound clip used to generate this spectrogram is available on the Current Tides website.

Photo Credit: Dan Hutt

endangered North Atlantic right whales; and in the polar waters near Alaska to determine habitat usage of bowhead whales prior to marine oil and gas exploration.

There are two main types of PAM surveys. In the first, an acoustic recorder is deployed for a long period of time – typically for months or sometimes for years – and can record terabytes of data at a single location. In the second, a ship may use its passive sonar system to monitor for the presence of marine mammals in real-time. Both of these survey strategies can have huge drawbacks if they rely solely on a human analyst to detect and identify (or classify) the species of the calling animal. In the first case, the tremendous volumes of data can take an analyst years to work through. Similarly, in the real-time scenario, the amount of incoming acoustic data may be overwhelming for the analyst, or the analyst may have other tasks that they need to perform so they cannot dedicate their full attention to marine mammal detection.

The obvious solution to this problem is to automate the detection and classification process. Researchers have been developing methods to do so for a couple decades and typical solutions rely on the time/frequency information of the signal. A common first step is to generate a spectrogram (see Figure 1 for an example) and examine how the frequency of a signal changes with time. Whale calls from different species have different characteristics and hence the spectrograms of their calls are unique. Some common signal features that may distinguish one whale species from another include the maximum or minimum frequency of the signal, or the presence of overtones (i.e., multiple discrete frequencies in a vocalization, as can be seen in the calls that make up the humpback whale song in Figure 1).

Developing a computer algorithm to automatically detect these patterns is especially difficult because they can be modified from their original values as the signal travels through the ocean from the source (whale) to the recorder. The ocean environment therefore limits the accuracy of automated systems since the signal distortion is dependent upon the properties of both the water and the boundaries (seafloor and surface), making it challenging to develop a reliable system capable of operating in many different environments.

It may sound like there are more problems than solutions, but it's still possible to deploy a hydrophone and recording system in the water, record whale calls, locate the vocalizations in the long acoustic record, and identify the species of the vocalizing whale. By doing this, we can (and have) learned a lot of valuable lessons about these enigmatic creatures of the deep. The goal now is to improve the reliability of automating this process.

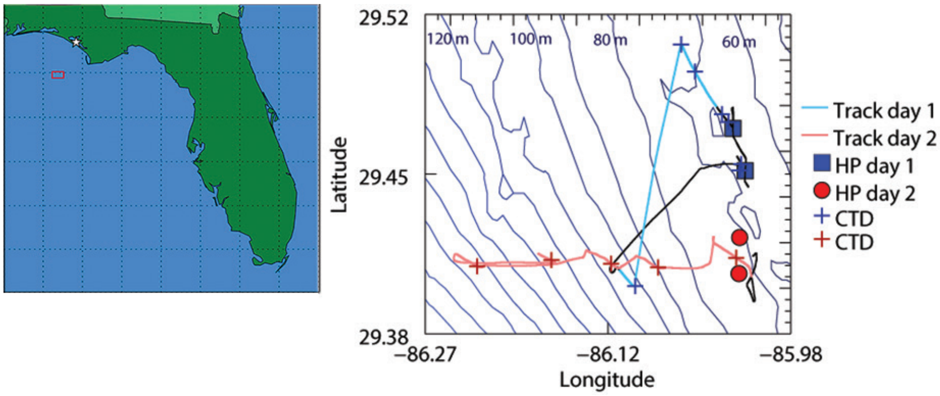


Figure 2. Map of the experimental location with Panama City, Florida represented as the white star, and the trial location in the area marked by the red box. The locations of the hydrophone (HP) moorings, ship's track, and CTD casts are shown on the zoomed in trial location map. Sea floor depth is represented by the contour lines.

Mimicking the human ear

To date, human analysts still do a better job than a computer at detecting and classifying whale calls. Incredibly, a human analyst can usually hear the difference between species' vocalizations even when the signals are significantly distorted as they travel through the ocean. My research group and I wish to leverage the power of human hearing, so the approach that we are taking is to use a novel type of automatic classifier that mimics the way in which humans discriminate between similar sounds. The system was developed at Defence Research and Development Canada (DRDC) and is referred to as an aural classifier. The signal features it uses to discriminate between calls from different whale species were motivated by musical acoustics research examining timbre. Timbre is often referred to as the "colour" of a sound, since it describes the characteristics of a sound that allow a listener to distinguish it from similar sounds of the same pitch and loudness; for example, middle C played on a guitar and piano sound different because they have unique timbre attributes.

As a first step, I have used this aural classifier to successfully identify calls from five different whale species. Now, I'm trying to assess the stability of these timbre-derived features as whale calls propagate through different ocean environments. For example, can the classifier still recognize a call regardless of the distance it travelled through the ocean?

Finding answers at sea

To study the effect of propagation on the performance of the aural classifier we performed at-sea experiments by transmitting two types of signals; the first were examples of real bowhead and humpback whale calls and the second were synthetic signals that mimicked calls from these species. We chose bowhead and humpback vocalizations because they make a challenging test case as they have similar frequency components and duration. The main experiment was conducted in the Gulf of Mexico, about 70 km southwest of Panama City, Florida as shown in Figure 2. We ran trials over two days in the spring of 2013 using DRDC's research ship, CFAV QUEST. The QUEST is one of the quietest research ships afloat which makes it uniquely suited to performing acoustics experiments. This means the data we collect are not contaminated by the noise of the research ship.

On both days we deployed two moorings, each with at least two hydrophones located at different depths within the water column. QUEST then moved a short distance (0.5–1 km) away from the recorders and transmitted the set of signals through the water while the ship drifted. The set of transmissions was

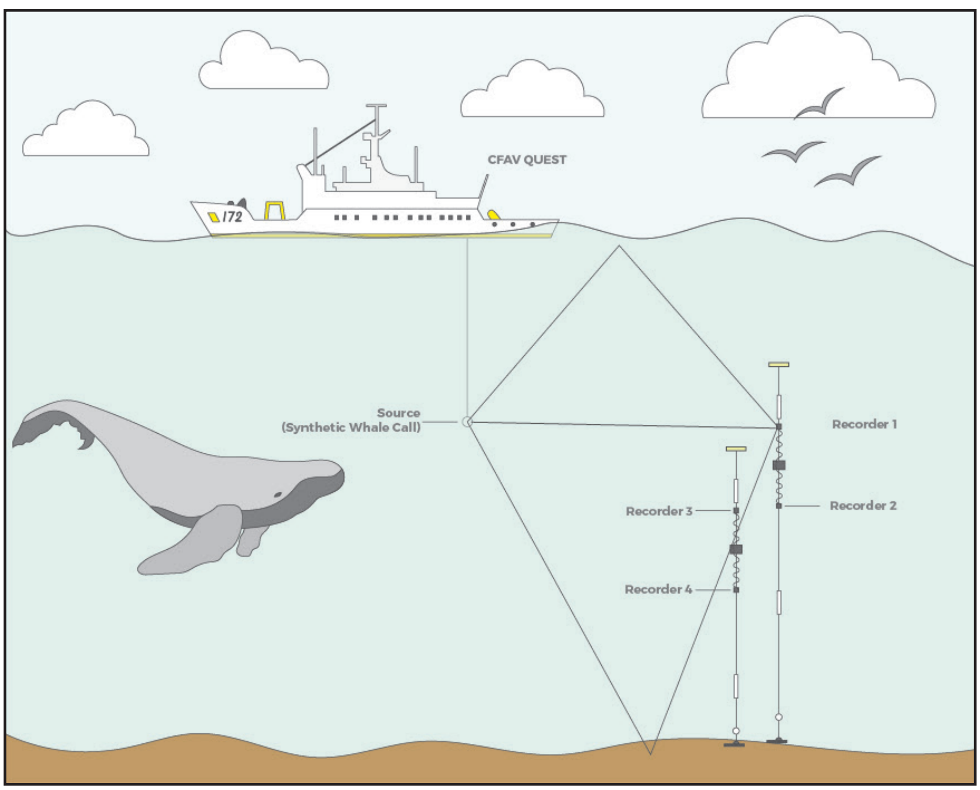


Figure 3. Cartoon of experimental set up. Real and synthetic whale vocalizations were transmitted from CFAV QUEST to hydrophones attached to the moorings. Each signal can travel different paths on its journey from the source to the recorders, causing distortion of the recorded signal. We're using data collected during the experiments to examine if this signal distortion affects our ability to recognize them with an automated system.

complete after about an hour. The ship then sailed further away from the recorders and repeated the process. In total, the signals were sent from five different ranges varying from 0.5 km to 20 km at the positions shown in Figure 2. A schematic of the experimental setup is shown in Figure 3.

The properties of the water were measured at both the mooring locations and the transmission stations. A conductivity-temperature-depth (CTD) instrument was used to measure the temperature and salinity which were used to calculate the variation in the sound speed as a function of depth. The sound speed profile helps us to determine the way in which the signal travels through the ocean and how much it interacts with the boundaries on its journey from source to receiver. We also determined the sediment type, so that the strength of the reflections off the ocean bottom could be estimated.

Training and using the classifier

Once back on land, the task of analyzing the data began. The overall objective is to determine how effective our aural classifier is at distinguishing between the bowhead and humpback whale calls for both the real and synthetic signals. Before this can be done, the classifier has to first be "trained" by computing the timbre-based features for each of the calls that were transmitted over the shortest distance. The computer is told the identity of each of the calls in the training set so that it can learn to recognize patterns in the perceptual features and hence distinguish between the calls from each species. The trained classifier is then applied to the signals that were transmitted over the longer ranges. This allows me to test the robustness of the classifier to propagation effects since the signals that travelled over longer ranges should be more distorted. This analysis is ongoing.

At the end of this research, I should have a good feel for how well the classifier can distinguish between whale species and how much the highly variable ocean conditions impact the classifier's performance. We hope that by leveraging some of the incredible power of the human ear we can develop a computer-based system that can quickly and accurately determine when whales are present. This would be a huge benefit when we're eavesdropping on the whales, as we continue to uncover the secrets of these enigmatic animals in the echoey ocean.

Carolyn Binder

Carolyn is a true Bluenoser, having grown up in Springfield, Nova Scotia. She left the province briefly to complete her BSc (Honours) in Physics at the University of Prince Edward Island. Then the beautiful coastlines and lush forests lured her back to Nova Scotia where she completed her MSc in Physics at Dalhousie University. She decided to stick around to do her PhD in Physical Oceanography at Dalhousie with a focus on ocean acoustics. The aural classifier has been an important part of both her MSc and PhD theses. This research is supervised by Dr. Paul Hines, formerly a senior scientist at Defence Research and Development Canada (DRDC).

Carolyn now works full-time as a Defence Scientist at DRDC while finishing up her PhD thesis. When not contemplating sound in the ocean she enjoys spending time outdoors, growing vegetables in her garden, and relaxing with her husband while waiting for the birth of their baby girl.

THIS RESEARCH WAS FUNDED BY THE OFFICE OF NAVAL RESEARCH, DEFENCE R&D CANADA, AND A NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC) PGS-D SCHOLARSHIP.

Getting to the Bottom of a Surface Current

Investigating the dynamics of the Nova Scotia Current

Mathieu Dever

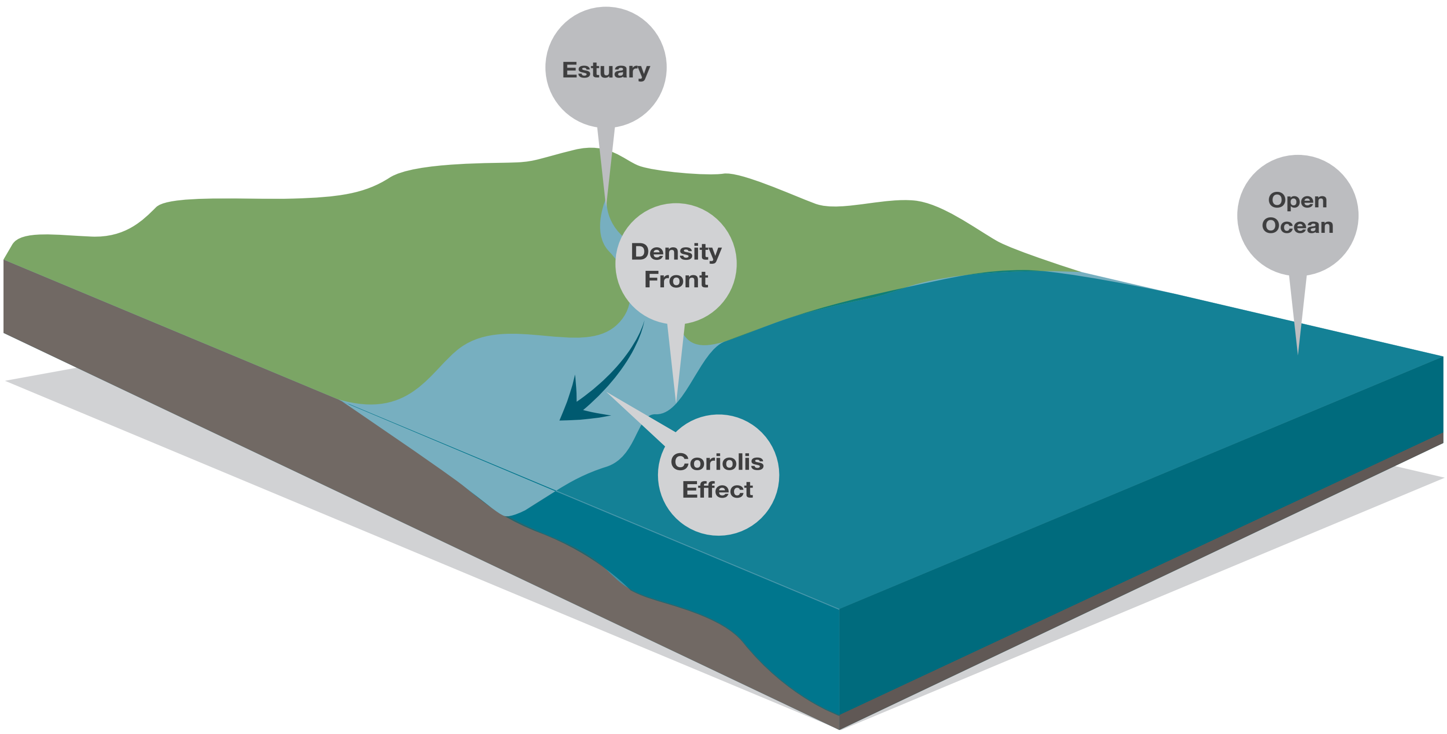


Figure 1. Coriolis effect in the northern hemisphere deflecting a river plume to the right, generating a density front between the light, fresher river water, and the heavier, saltier open ocean water.

Imagine you are sitting on a merry-go-round spinning counterclockwise and you decide to throw a ball straight in front of you. To your eye, the ball will unexpectedly curve to the right and land closer to you than you initially thought. Excited by this newly discovered super power, you make your friends stand on a balcony overlooking the merry-go-round and repeat the experiment. But there is a problem – none of your friends see the ball curve: to them, the ball does indeed move in a straight line!

The reason you see the ball curve, while your friends see it go straight, has to do with your differing frames of reference: to people standing on the rotating frame (i.e. the merry-go-round), the ball appears to curve, while to everyone observing the movement from a fixed frame (i.e. the balcony) the ball appears to travel in a straight line. Because most of us (hopefully!) live on our spinning earth, this phenomenon of motion along a curved path is often observed and is known as the Coriolis effect. A classic illustration of this phenomenon is the infamous legend that if you drain the water from a full sink in the northern hemisphere, the water will tend to flow clockwise, as opposed to flowing counterclockwise in the southern hemisphere. While this is not actually observable in sinks, nor toilet bowls – as the legend would lead you to believe – it is most definitely observed in ocean currents where the scale of the motion is much larger.

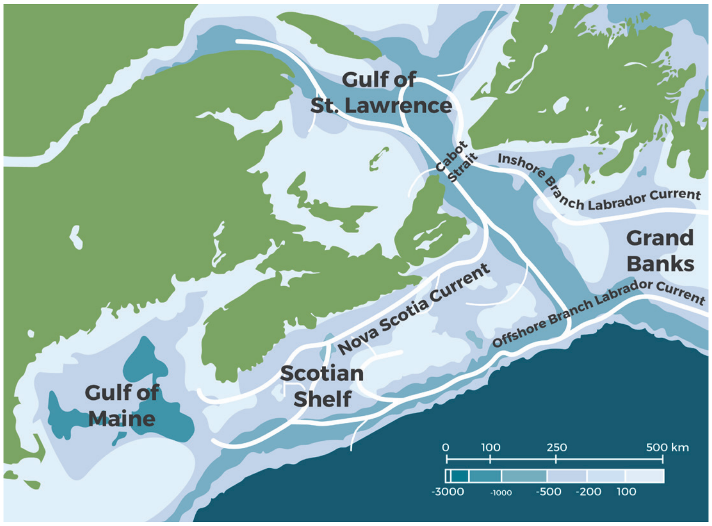


Figure 2. Map of the Scotian Shelf and its surroundings showing the Nova Scotia Current flowing from the western Gulf of St. Lawrence to the Gulf of Maine through Cabot Strait.

One example of the Coriolis effect is the trajectory of river plumes being discharged in the open ocean: the freshwater that is exiting the river will veer to the right in the northern hemisphere and flow along the coast (Figure 1). This exact mechanism is observed on the eastern coast of Canada, along the coast of Nova Scotia, where a strong coastal current flows towards the Gulf of Maine. This current is known as the Nova Scotia Current (Figure 2), and originates from Cabot Strait, where a large outflow of colder and fresher water from the St. Lawrence River is discharged onto the Scotian Shelf. Subjected to the Coriolis effect, the surface current veers right by 90° around Cape Breton Island, to flow southwestward along the coast of Nova Scotia at a speed of about 1 km/hr.

What drives the Nova Scotia Current?

Knowing where the current comes from and where it is located is important, but to truly understand how and why it changes with time and space, we also need to understand the mechanisms that drive it. In other words, what forces are pushing the Nova Scotia Current along and affecting its direction and speed?

It is worth remembering that the water flowing within the Nova Scotia Current originally comes from the St. Lawrence River and is therefore considerably fresher than the ocean water that is already present on the Scotian Shelf. It is easy to realize that water carrying salt would be denser and, therefore, heavier than freshwater. This large difference in water density is one of the key contributors to the Nova Scotia Current. The greater the density difference is, the faster the current moves along the coast. The outflow of freshwater from the Gulf of St. Lawrence varies a lot with seasons: the river flow is very large in spring when the snow is melting, and is much smaller in the winter. The Nova Scotia Current therefore exhibits large flow variations over the period of one year. This forcing mechanism that generates motion based on the density difference of two water masses is referred to as “buoyancy forces” and explains why the Nova Scotia Current is sometimes referred to as a buoyancy-driven, coastally-trapped current.

While it has been demonstrated that the motion of coastally-trapped surface currents can largely be explained by considering buoyancy forces alone, there are also other competing forces that generate variability in the strength and location of the currents. One major mechanism that affects the Nova Scotia Current is the surface wind stress. When the wind blows on the surface of the ocean, the friction between the

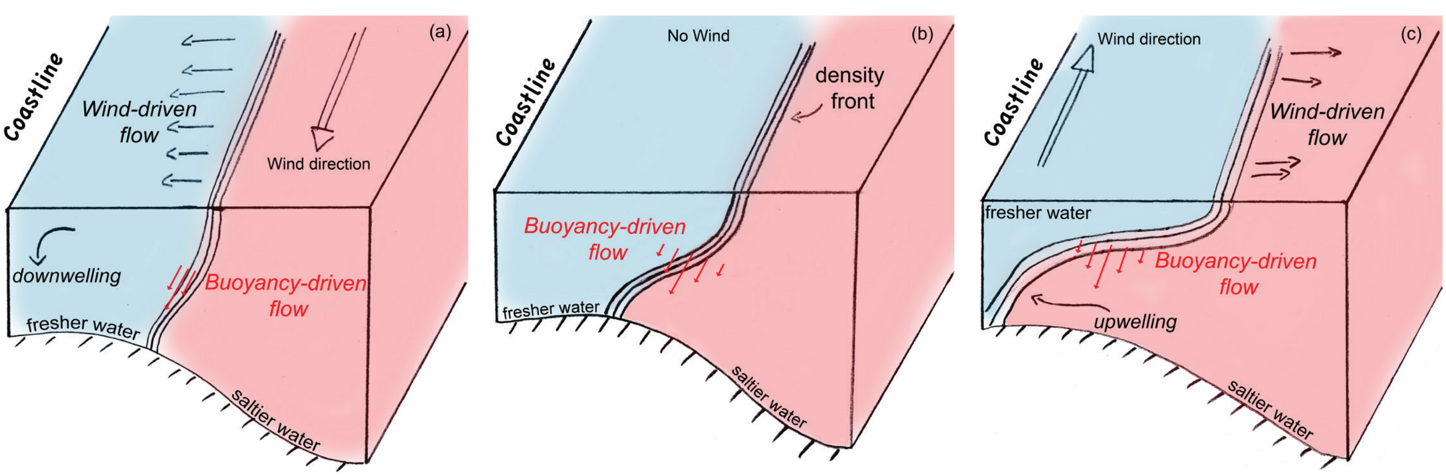


Figure 3. Buoyancy-driven and wind-driven flow in (a) downwelling-favourable conditions, (b) steady state (i.e. no wind) and (c) upwelling favourable conditions.

air and the water generates a current in the upper part of the ocean. A Swedish oceanographer from the early 20th century, named Vagn Walfrid Ekman, demonstrated that the wind-generated current is directed at 90° to the right of the wind, once again because of the Coriolis effect. Because of this, winds directed along the coast affect the three-dimensional structure of the current. If the wind is blowing with the coast to its left, water is pushed offshore (i.e. to the right of the wind). Because no water can come from the land, the water that must replace what is pushed offshore must come from below: this is called “upwelling” (Figure 3c). The opposite is also true; when the wind blows with the coast to its right, surface water is forced towards the shore. Because this new water cannot pass the coastline, it has to go deeper: this is called “downwelling” (Figure 3a).

Wind-driven and buoyancy-driven forcing mechanisms are constantly competing to drive coastally-trapped surface currents, such as the Nova Scotia Current, but very little is known regarding which one of these processes dominates. The balance of the forces is highly dependent on both the location and the time of year.

The importance of the Nova Scotia Current

Ocean circulation and major ocean currents have been studied since the early days of ocean exploration, as they can significantly affect navigation. During the 19th century, a series of canals were built to develop a reliable seaway connecting the Great Lakes to the Atlantic Ocean. This, combined with the shipping lane connecting Europe to the American eastern seaboard, placed the Scotian Shelf and the Nova Scotia Current in the heart of one of the busiest shipping lanes in the world.

Navigation, however, is not the only reason the Nova Scotia Current generates a lot of interest. Recent studies using fish tracking techniques suggest that many marine species (whales, sharks, salmon, etc.) migrate through this region when relocating from their feeding grounds to their spawning grounds, and vice versa. It is hypothesized that changes in ocean circulation affect the migratory behaviour of these species. Commercial fishing in this region is a multi-billion dollar industry, thus any change in fish behaviour or distribution could have major repercussions on the local economy.

A better understanding of coastal circulation would also be beneficial to the study of pollutant dispersal along populated shores, as well as search and rescue planning in a region that contains heavy marine traffic.

How do we measure it?

As mentioned above, we know that the Nova Scotia Current is mainly driven by winds and buoyancy forces, but we don’t understand the balance of these two forces. The major challenge is to develop a reliable technique that separates and quantifies the respective contribution of these two mechanisms to the total observed flow.

The wind-driven flow is the easy part: it can be estimated based on the wind speed, of course, but also on parameters, called friction coefficients, which represent how well the wind’s energy is transferred to the ocean. The relationship is linear and positive: the faster the wind blows, the faster the current flows.

Figure 4. Picture of a Slocum glider in Bedford Basin, Nova Scotia. Photo Source: http://gliders.oceantrack.org/

The estimation of the buoyancy-driven flow is a lot trickier. It relies on two major characteristics of the current: the first, as previously detailed, is the density difference between coastal water and ocean water; while the second is related to the steepness of the interface density front between these two water masses (Figure 3b). The steeper this front is, the faster the buoyancy-driven current will be.

But, how do we measure these two characteristics? For my project, we rely on ocean gliders (Figure 4). These vehicles are just like regular gliders (i.e. unpowered airplanes), but are used, instead, to “fly” underwater and measure the water density (among other things). Ocean gliders are very energy efficient and can therefore sample the ocean for weeks at a time, in a cost-effective way. The gliders travel up and down in the water column by inflating or deflating a ballast bladder contained in its nose, which alters the glider’s buoyancy. Wings are used to project some of the glider’s vertical momentum into the horizontal direction, which allows the glider to travel underwater for several kilometers before having to inflate/deflate its bladder. This spatial coverage, combined with the high sampling rate of all onboard instruments, allows for a very good resolution of the shape and time evolution of the Nova Scotia Current, which allows us to quantify the buoyancy-driven component of the flow. Other measurement techniques, such as shipboard measurements or fixed sensors, are both expensive and limited in space and time.

Results show that the respective contribution of winds and buoyancy varies greatly in both space and time. The wind-driven flow is fairly consistent over the entire Scotian Shelf, but varies in strength throughout the year: winds are generally stronger in the winter, and more upwelling-favorable in the summer (which tends to slow down the current). The buoyancy-driven flow is the strongest in the winter and weakest in the summer - therefore exhibiting a lag with respect to the seasonal cycle of the river discharge. The buoyancy-driven flow also varies in space: as the current travels towards the Gulf of Maine, the density front erodes due to mixing processes, therefore weakening the buoyancy-driven flow. While this is true for the Nova Scotia Current, it is not necessarily the same for other buoyancy-driven, coastally-trapped currents. One of the most attractive aspects of our approach is that it is not specific to the Nova Scotia Current and can be applied to any coastally-trapped surface current! Such currents can be found all over the world: along the coasts of Norway, Australia, Greenland, Alaska, and many other regions. This project will bring us one step closer to finally getting to the bottom of these complicated surface currents.

THIS WORK WAS FUNDED PRIMARILY BY THE OCEAN TRACKING NETWORK CANADA (OTN), THROUGH A NETWORK PROJECT GRANT FROM THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC). ADDITIONAL SUPPORT WAS PROVIDED BY THE CANADIAN FOUNDATION FOR INNOVATION (CFI) AND THE SOCIAL SCIENCES AND HUMANITIES RESEARCH COUNCIL (SSHRC).

Mathieu Dever

Born in Versailles, France, Mathieu has always been fascinated by the ocean and its dynamics. It was in high school that Mathieu realized that working in oceanography would guarantee him to not only live by the ocean, but also to be able to work outdoors while pursuing his love for the sea. After completing his undergrad in physics and chemistry at the University of Ottawa, Mathieu finally committed to the oceanography route by going to the National Oceanography Centre in Southampton, England, where he completed his Masters in Physical Oceanography and Meteorology. Now at Dalhousie University to complete his PhD, under the supervision of Dr. David Hebert and Dr. Jinyu Sheng, Mathieu’s research focuses on the large-scale dynamics affecting buoyancy-driven, coastally-trapped currents such as the Nova Scotia Current, and its relationship with fish migration behavior and pattern.

Digging Into the Past

Reconstructing dust fluxes in sediment cores using grain size distribution

Diksha Bista

Although time travel is not currently possible, there are now many technologies that allow scientists to effectively go back through time, often by millions of years. Using these techniques, many discoveries about the history of the Earth have been made, such as periods of extreme hot or cold, volcanic eruptions and the extinction of dinosaurs. In fact, over the Earth's 4.5 billion year existence, it has undergone many natural changes. However, current human impacts are drastically accelerating some of these natural perturbations. As such, we need to use these technologies to understand how the Earth historically responded to natural changes in both the atmosphere and the climate. This will hopefully allow scientists to monitor and mitigate changes caused by humans in the future.

Since the formation of the Earth, the composition of the atmosphere has been changing continuously. An important, and highly variable, component of the atmosphere is dust, which has both direct and indirect effects on the Earth's climate. Directly, dust affects the amount of solar radiation (i.e. sunlight) reaching the Earth's surface. If the dust reflects the incoming radiation back into space, the Earth will experience cooling; alternatively, if the dust absorbs the radiation, the Earth will warm. Indirectly, dust affects Earth's energy balance by promoting cloud formation. Low, thick clouds will reflect more of the incoming solar radiation, therefore decreasing the amount of energy reaching the Earth's surface. Dust also indirectly affects the marine biogeochemical cycle by delivering iron, an essential but limiting nutrient, to the ocean. This can stimulate biological productivity in regions where iron is scarce and can increase the export of organic carbon to the deep-sea, which ultimately affects the concentration of CO_2 in the atmosphere. Overall, on a longer time scale, both the direct and indirect impacts of dust can play an important role in climate change.

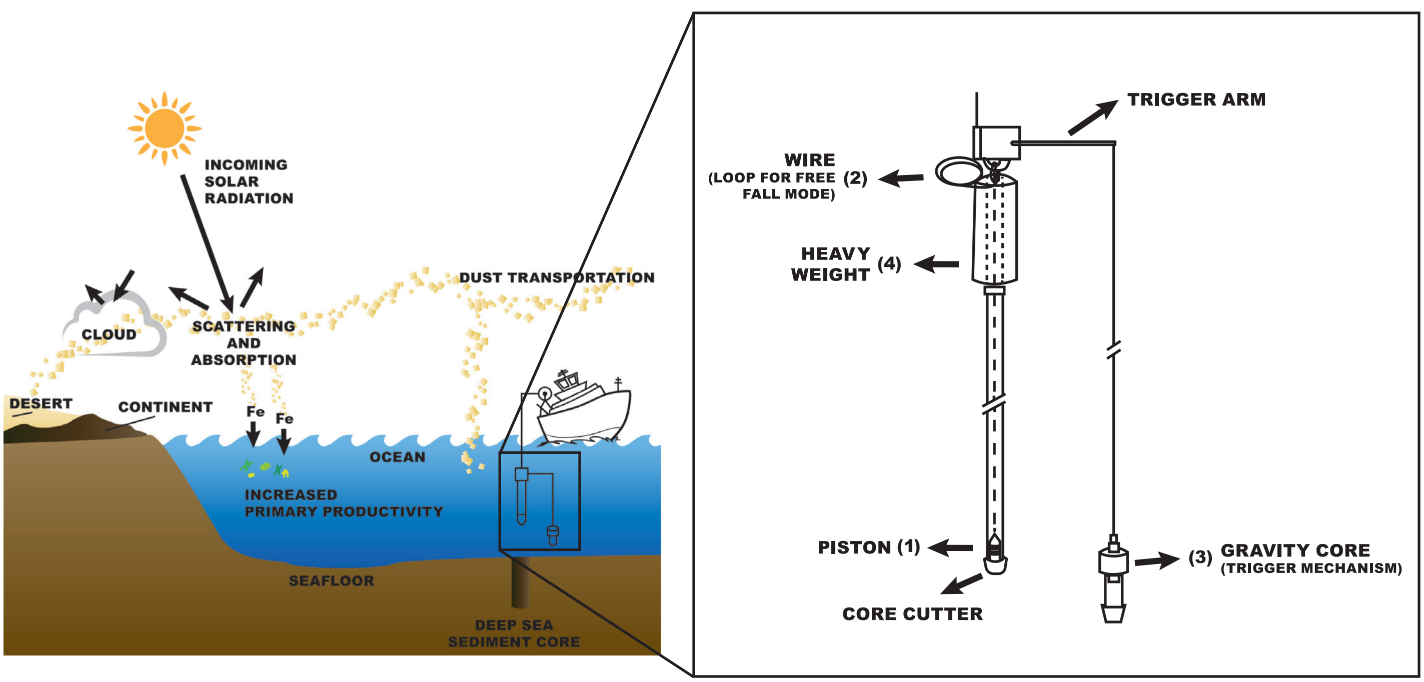


Figure 1. Left: Schematic showing the interaction between dust and other components of the Earth's system. Right: Schematic of a standard piston core.

What happens at sea?

Atmospheric dust originates from the breakdown of continental rocks and is transported by the wind over long distances. Based on the strength of the wind and the atmospheric circulation, dust can be transported as far as the middle of the ocean, where it sinks and is then deposited on the seafloor. Sediments in the deep-sea, including dust from the continents, accumulate slowly at a rate of 1 – 20 mm per thousand years and are preserved sequentially on the seafloor. Newer material are therefore found near the surface, whereas deeper sediments are linked to events further back in time. This chronological sediment sequence and slow accumulation rate allow scientists to gain insight on a few thousand years of the Earth's history by analyzing only a few centimetres of sediment.

To do this analysis, deep-sea sediment samples are collected during research cruises using various coring techniques. The technique that was used to collect my samples, is called piston coring and is shown schematically in Figure 1. The corer uses a tight fitting piston (1) inside a core barrel. The piston is attached to a wire (2) that pulls the piston up during penetration into the seafloor, creating a suction to hold the sediment in place. A short gravity core is used as a trigger mechanism (3) that hangs several metres below the base of the piston core. Once the gravity core reaches the seafloor, this triggering mechanism releases the piston core and it falls freely into the sediment. The penetration energy is increased by heavy weights (4) that are fitted on the top of the barrel. Although the length of the piston core varies depending on the nature of the sediment, most cores are about 20 m in length. Once the core is extracted and onboard the ship, it is cut into 1 m length sections. Each section is then cut in half lengthwise, one half is used as the working half of the core, and the other half is left untouched and stored in a core repository for future research.

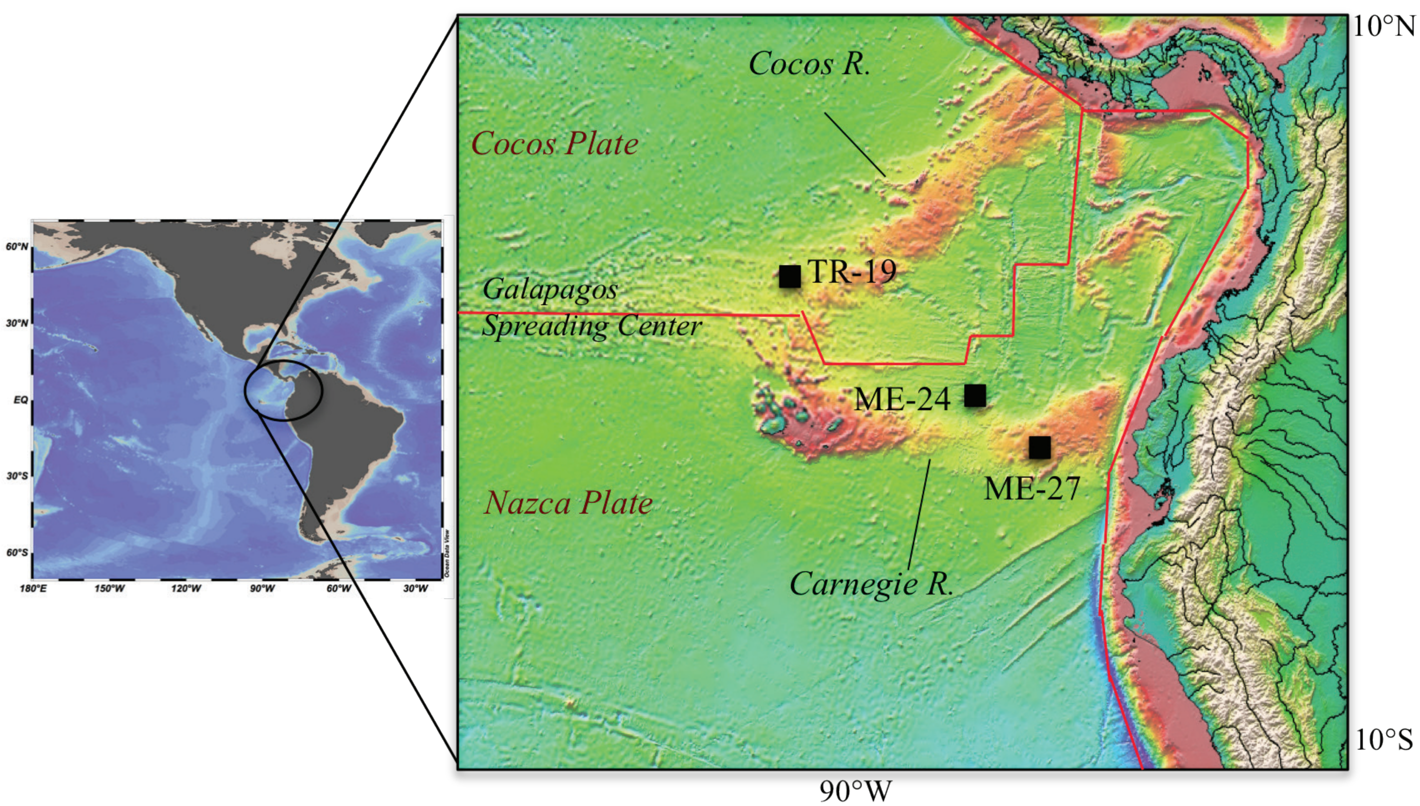


Figure 2. Map of the core sites from the eastern equatorial Pacific region. (Source credit: http://topex.ucsd.edu/marine_topo/mar_topo.html)

Figure 3. Deep-sea sediment sample under a scanning electron microscope. (a) Bulk sediment, (b) organic carbon and carbonate free sediment, (c) inorganic sediment (i.e., organic carbon, carbonate and silica free sediment).

From sea to the lab

Once the core samples are brought back to the lab, various analyses are performed, depending on the research focus. For my research, I analyze sediments from the eastern equatorial Pacific region, which is shown in Figure 2. By determining how the dust concentration changed over the last 30 000 years we hope to better understand the interaction between dust and the Earth's climate. This knowledge will be used to provide a better constraint for the impact of dust in numerical simulations of the future climate.

One approach to estimating the dust concentration in the cores is to examine the sediment grain size distribution. Research has shown that the size range of dust grains transported to the deep-sea is often less than 5 μm (0.005 mm). This is because sediment grains larger than 5 μm are too heavy to be transported by wind over a long distance and hence fall into the ocean closer to the source region. Therefore, dust deposited on the seafloor further away from the source shows a peak between 1 - 5 μm in the sediment grain size distribution.

Dust is composed of inorganic (i.e. non-living) material, so to obtain the grain size distribution of my samples, I first need to remove all the "biogenic" material from my core samples. These biogenic materials appear in sediments in the form of organic carbon, calcium carbonate and silica and are typically derived from phytoplankton debris. Using hydrogen peroxide, hydrochloric acid and sodium carbonate, I can dissolve all biogenic materials, resulting in a sample of purely inorganic sediment. Sediments after the removal of biogenic materials, as seen under a scanning electron microscope, are shown in Figure 3. A Coulter Counter is then used to analyze the grain size distribution of the sediment. It operates on the principle that a particle passing through an electric field will cause a voltage impedance proportional to the particle volume. The Coulter Counter returns the volume distribution of the grain sizes (i.e. the ratio of the volume of each sediment size class to the total volume of inorganic sediment). The results from two samples, obtained from different depths in the sediment core, are shown in Figure 4. Using this information and knowledge of typical dust grain size, I can determine the contribution of dust to the total sediment volume as a function of depth and hence, produce a dust record for the past 30 000 years.

My results show that dust fluxes in the eastern equatorial region were highest when the Earth was transitioning from a full glacial period (about 19 000 years ago), when most of the northern hemisphere was covered in ice, to today's warmer interglacial conditions (last 10 000 years). Previous studies have indicated that conditions were drier in the Northern subtropics during this period, which is one of the major source regions for dust. These drier conditions increased dust mobilization and, when coupled with the stronger atmospheric circulation, enhanced the dust transport to the eastern equatorial Pacific, resulting in the observed dust peak in my sediment cores (see Figure 4). The changes in dust flux over 30 000 years, including the dust peak during the glacial-interglacial transition period, show that dust concentration in the atmosphere was not only affected by different climatic conditions but also may have had a major impact on past biological productivity and the Earth's energy balance, thus influencing past climate.

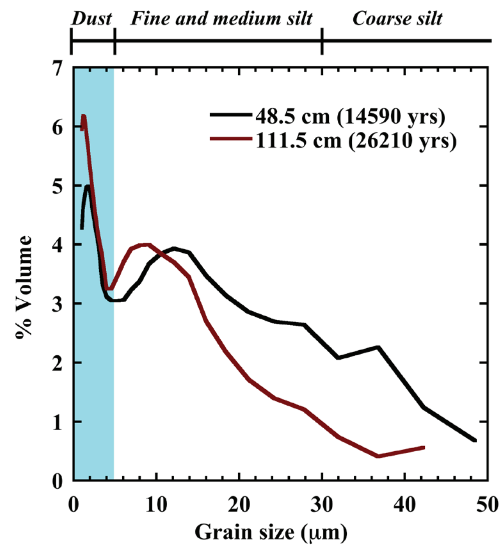


Figure 4. The inorganic grain size distributions of the eastern equatorial Pacific sediment at two different depths. Blue area highlights the 1 - 5 μm size range containing dust peaks. Corresponding ages of the sediment are indicated in the legend.

Overall, my research is a powerful example of how sediment dust records for the last 30 000 years can reflect changes both in the atmosphere and on the continents. It also demonstrates that deep-sea sediment coring can be used to piece together the many components that impact the Earth's climate. The study of down-core sediment, not only offers a way to investigate events in the Earth's history, but also enhances our knowledge of the interactions between the atmosphere, the ocean and the continents. Understanding how these components interact, allows scientists to create a baseline for predicting future climate change. Until time travel is invented, we will need to continue using deep-sea sediment coring to better understand the Earth's past climate so that we can distinguish between variability caused by natural fluctuations and that caused by human activity.

THIS RESEARCH WAS FUNDED BY THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC).

Diksha Bista

Coming from a land locked country, the idea of studying the ocean was never in the future plan for Diksha Bista until she came to Bremen, Germany for an undergraduate degree in Earth and Space Sciences. Having never seen the ocean, her first year courses on oceanography, along with various field experiences, opened up a whole new world for her. By the end of her undergraduate degree, she had decided to pursue her interest in oceanography. In 2012, she joined Dr. Stephanie Kienast as a geological oceanography master student at Dalhousie University. She has now completed her degree and will soon start a PhD program at the University of Bristol in the United Kingdom. In her free time, she enjoys movies, music and a good book with a cup of coffee.

The Regenerative Capacity of Colonial Organisms: an Age-Old Dilemma

Estimating mortality of an invasive, rapidly growing and regenerating bryozoan

Danielle Denley

UFO (Un-invited Foreign Organism) sightings

Since the early 1990s, dramatic changes have been occurring off the Nova Scotian coast. Several feet offshore and about 10 metres underwater – completely unnoticeable from the beach – an alien invader has been quietly making itself at home in Nova Scotia's rocky subtidal zone…and it is not a welcome house guest!

The British Invasion: a European bryozoan on the Canadian coast

Biological invasions are the introduction of non-native species into a habitat they did not previously occupy. These invasions often occur as a result of human activities such as shipping and imports for fisheries or aquaculture. For example, fouling species like bryozoans are often transported among major shipping ports, either as adults attached to the hulls of ships or as planktonic larvae in ships' ballast water.

In temperate coastal ecosystems, marine invasions are increasing worldwide and are considered to be one of the major human-mediated threats to local biodiversity. They can lead to significant changes in the ways in which species interact and how ecosystems function. One of the most prevalent invasive species introduced to Nova Scotia over the past two decades is the bryozoan *Membranipora membranacea* (Figure 1), which was likely introduced from European waters via ballast water. *Membranipora* was first observed in the Gulf of Maine in 1987, where it dramatically changed the local marine community in just two years. From the Gulf, it spread north and was first recorded off the southwestern shore of Nova Scotia in 1992.

What makes this bryozoan so destructive to the ecosystem is its impact on large seaweeds called "kelps". Kelps are typically found in kelp beds (Figure 2) which are the underwater equivalent of forests. These beds provide an important source of food and habitat for many marine species, including sea urchins, lobsters, and juveniles of commercially important fishes. *Membranipora* grows predominantly on kelp, and during certain times of the year can cover up to 90% of an individual kelp blade. Encrustation by *Membranipora* reduces both growth and survival of kelp by breaking down the underlying tissue and weakening the kelp blades. This makes them more likely

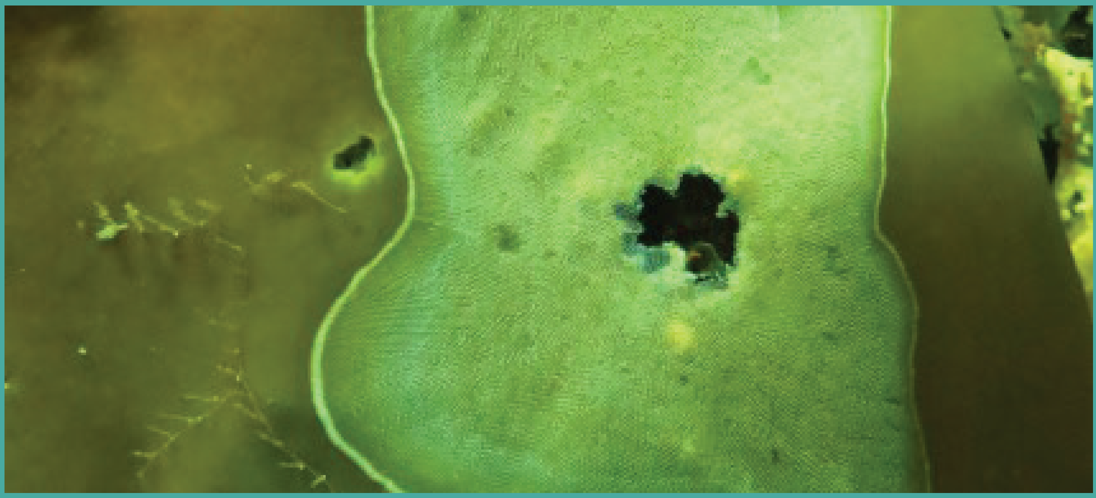
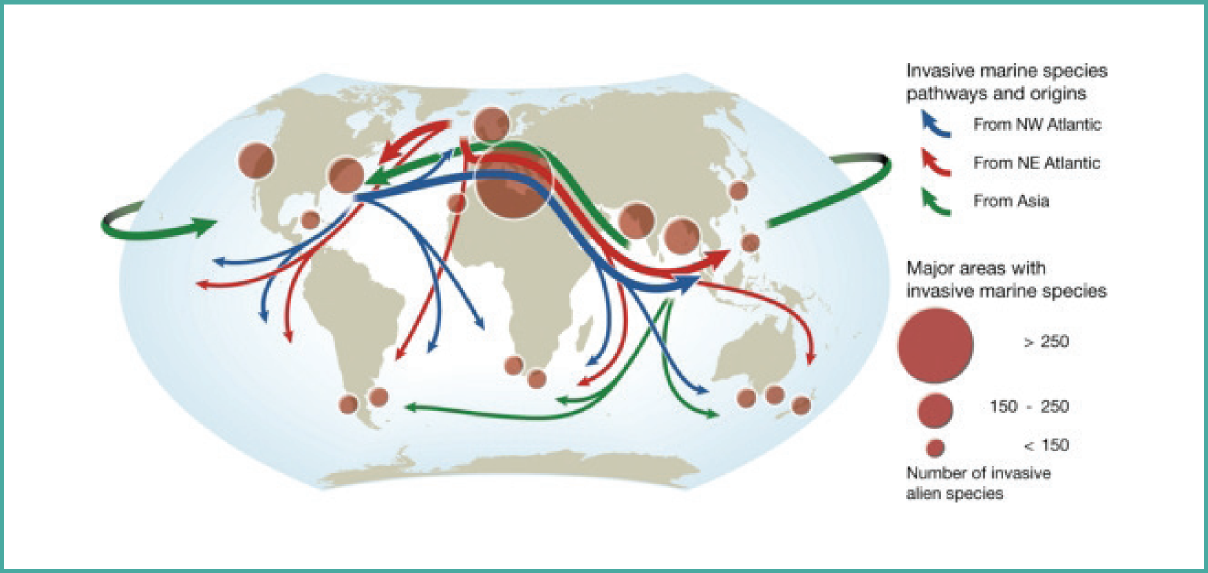


Figure 1. Colony of *Membranipora membranacea* growing on the kelp *Laminaria digitata* at Sandy Cove in Terence Bay, NS. Photo Credit: Robert Scheibling.



Major pathways and origins of invasive species infestations in the marine environment. . By Hugo Ahlenius, In UNEP/GRID-Arendal Maps and Graphics Library (February 2008). Available online at: http://www.grida.no

to break and tear during seasonal storms when strong waves move the water and kelp underneath the surface.

In Nova Scotia, the introduction of *Membranipora* has led to marked defoliation of kelp beds and is estimated to be responsible for up to 70% reduction in kelp canopy cover annually (Figure 3). Not surprisingly, the ability of this invasive species to alter coastal habitats has generated significant concern among ecologists, and the community as a whole, for the welfare of economically and ecologically important species, including lobsters and sea urchins. If *Membranipora* spreads further north as a result of warming ocean temperatures, we could see a dramatic loss of kelp beds throughout the northwest Atlantic.

Colonialism (biologically speaking)

Most research on *Membranipora* in Nova Scotia has focused on understanding its population dynamics (i.e. how fast it grows, how often it reproduces, and how long it lives) to more accurately predict population outbreaks and range expansions. However, quantifying the population dynamics of this species is complicated by the fact that it is a colonial organism, which means that an individual colony is actually composed of tens to thousands of semi-autonomous units or modules. The most well known examples of colonial organisms in the marine world are corals, which form compact colonies made of many identical individuals called polyps. In *Membranipora*, these identical individuals are called zooids. Unlike reef-building corals, which have three-dimensional structure, *Membranipora* forms flat

Figure 2. Mixed kelp bed at Sandy Cove in Terence Bay, NS. Photograph taken in June 2012. Photo Credit: Robert Scheibling.

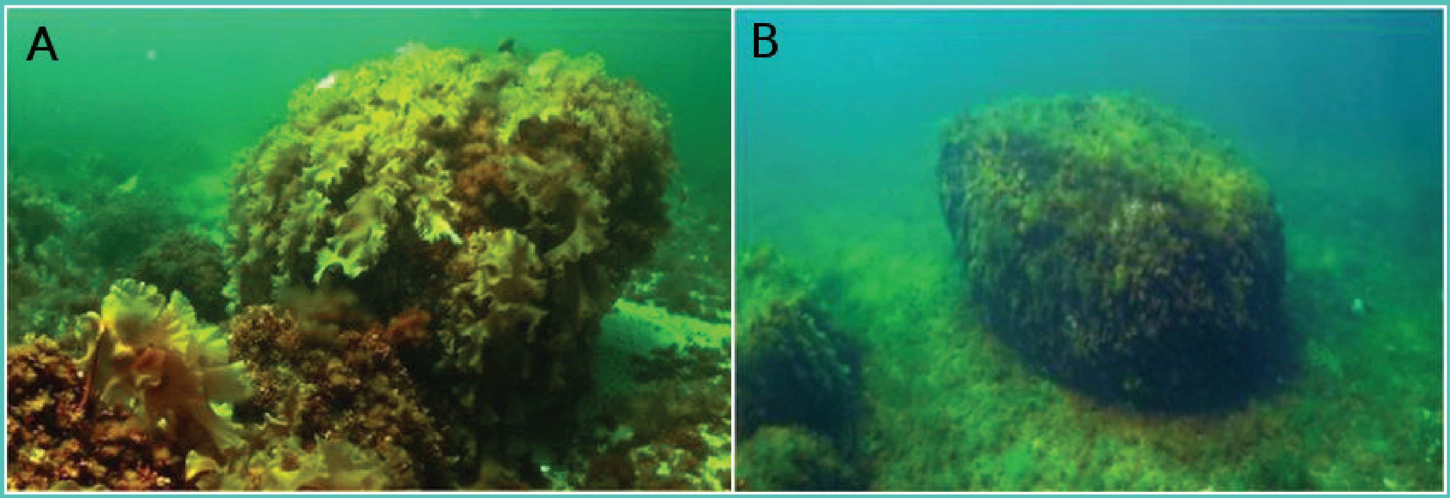


Figure 3. (A) Sugar kelp (*Saccharina latissima*) growing on a boulder at Paddy's Head in St. Margarets Bay, NS in June 2012. (B) Boulder from A photographed again in June 2013 following loss of kelp at Paddy's Head, due in part to heavy encrustation of kelp by *Membranipora membranacea*. Photo Credit: Robert Scheibling.

circular colonies that grow through the addition of new zooids to the colony edge. This creates an age gradient within the colony, with the oldest zooids at the centre and successively younger zooids towards the colony edge.

Because mortality (i.e. death) for each individual zooid occurs independently and new zooids are continually being produced to replace those that have died, modular loss (i.e. loss of individual zooids) may not necessarily lead to colony-wide mortality. This makes *Membranipora* extremely resilient!

Secrets of success

There are several characteristics of *Membranipora* that contribute to its success as an invader of our coastal waters:

1) It outcompetes the native bryozoan species *Electra pilosa*.
2) It invaded a largely unoccupied habitat (kelp blades).
3) It has no major predators in the northwest Atlantic.
4) It grows rapidly.
5) It has a remarkable capacity to regenerate following damage.

One component of my research focuses on addressing this last characteristic: What is the capacity of *Membranipora* colonies to recover from damage? Specifically, I want to know if there is a damage threshold for colonies from which full recovery would not be possible. I also want to know if either the water temperature or the location of damage within a colony affects recovery capacity. In short: is it possible to kill a regenerating colonial organism like *Membranipora*, or will colonies simply continue to regenerate indefinitely?

Let the games begin

For the past three years, I have been studying the population dynamics of *Membranipora* by SCUBA diving at sites along the southwest coast of Nova Scotia. In order to measure seasonal mortality of *Membranipora*, which typically occurs in the late fall to early winter, I have to dive year-round. After spending a couple of winters diving in 0°C seawater, only to discover that *Membranipora* colonies were somehow persisting in spite of the cold, I decided it was time to try a laboratory-based approach!

Laboratory experiments have allowed me to study the recovery capacity of *Membranipora* in a controlled environment, where I have focused on the effects of the three factors I was interested in (water temperature, the amount of damage, and the location of damage within a colony). To achieve this, I collected kelp blades with *Membranipora* colonies growing on them from Sandy Cove in Terence Bay, NS, and brought them back to Dalhousie's Aquatron facility. I then distributed the colonies evenly among three flow-through seawater tanks, each maintained at a different temperature (5°C, 12°C, and 20°C). The temperatures were selected to represent seasonal variation in our regional ocean temperature, from 5°C in early winter to 20°C in late summer.

After allowing *Membranipora* colonies to acclimate at these temperatures for one week, I began damaging colonies artificially by scraping individual zooids off the kelp with a scalpel, removing either 50% or 75% of their surface area. Using different levels of damage allowed me to determine whether colonies experience a damage threshold from which full recovery through regeneration is no longer possible.

To examine the effect of the location of damage on the recovery capacity of colonies, I damaged either the colony periphery (younger, growing edge) or the centre (oldest section). I also allowed some lucky colonies to remain intact as controls! Once the damage had been done, I photographed the colonies weekly and measured the change in colony surface area over time to look for signs of colony recovery.

The Achilles heel

After two weeks, I saw some surprising results: the amount of damage inflicted did not affect the colonies' ability to recover, even under the coldest temperature treatment. Instead, colonies with younger zooids removed showed no signs of growth or recovery and colonies with older zooids removed continued to grow along their outer edge — regardless of the temperature or how much damage they had suffered. In other words, damage to the edges of colonies is more likely to lead to colony-wide mortality than damage to the centre of colonies. It is possible that colonies can only continue to grow and recover following injury if the remaining zooids within the colony are below a certain age. Once individual zooids get too old, they appear to lose their ability to divide, and as a result "older" regions of *Membranipora* colonies are unable to regenerate.

I hope I die before I get old: talking about my (re) generation

The inability of *Membranipora* zooids to divide indefinitely provides some hope for the survival of kelp beds in Nova Scotia. During an outbreak, the density of colonies is often so high that colonies are forced to grow into one another due to a lack of available area on the kelp blade. But when colony edges meet, growth stops because neither colony can grow over or around the other. During this standoff, peripheral zooids will be aging with no opportunity to divide, and if growth is delayed for long enough, the colonies involved may no longer be able to produce new zooids, even if one of the competing colonies dies or is removed due to erosion of the kelp blade.

Breakage of *Membranipora* encrusted kelp blades is damaging not only to the kelp, but also to the colonies growing on it. Kelp blade breakage and erosion often result in the loss of peripheral, younger regions of *Membranipora* colonies that are closer to the more fragile and actively eroding edges of the kelp blades. This means that *Membranipora* may in fact be its own worst enemy in that by weakening the tissue of its host kelp blade, it self-inflicts damage from which it cannot recover. It is possible that this lack of colony growth following damage to peripheral zooids may allow kelp beds valuable time to recover after storm events when damage to kelp, and colonies, is most extensive.

So, after all is said and done, I've still only answered the second part of my original question: is it possible to kill a regenerating colonial organism like *Membranipora*, or will colonies simply continue to regenerate indefinitely? As it turns out, *Membranipora* colonies cannot regenerate indefinitely. So the question remains, although slightly re-phrased: can you kill a colonial organism that can only regenerate until its remaining zooids reach a critical age threshold? I would like to think that you can – our valuable local marine ecosystem is dependent upon it.

THIS RESEARCH WAS FUNDED BY THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC).

Danielle Denley

Danielle is originally from Canada's west coast. Growing up on Vancouver Island instilled in her a real love and respect for the ocean. As a toddler she had a healthy curiosity about intertidal organisms, and some of her earliest marine biology experiments involved rather destructive sampling techniques – including pulling sea stars of off rocks to observe their tube-feet, removing tube-worms from their calcareous tubes, and taking crabs home from the beach in her pockets. Since then, her interest in marine ecosystems has only increased, leading her to become SCUBA certified in order to experience subtidal ecosystems first hand, as well as, to conduct SCUBA-based field experiments as part of her PhD research. During her breaks from fieldwork, Danielle has enjoyed exploring the East Coast through activities such as hiking, camping, cross-country skiing, and kayaking. Photo Credit: Robert Scheibling.

A Ripple in Time

Using a novel acoustic instrument to study the flow of water over sand ripples

Jenna Hare

The feel of soft sand beneath your feet, the sound of crashing waves and the sight of curious animals darting into and out of view make beaches remarkable places to explore. But have you ever wondered about the natural forces that shape the very beach you are standing on? Or how undulating patterns (Figure 1) get written in the sand with every passing wave? As a child, I asked these questions, and now, as a student in oceanography, I am conducting research to answer them.

Waves and currents are constantly acting upon beaches by carrying sand to and from the shore. This process creates ripples, which influence the flow of water itself, and so alters the shape of the ripples. This continuous feedback between water and sand plays a key role in large-scale processes such as beach erosion and long-term changes in the shoreline. My research challenge is to measure the specific processes that occur at the dynamic interface between sand and water. However, accurately measuring the water motion just above the sand requires advanced sensors that can “see” changes in the flow over millimetre scales. The difficulty of making these measurements on such a fine scale is amplified on a real beach and so I have transported the sand to a large tank in the lab. In this way, I can control individual variables such as water speed, sand grain size and water depth without having to worry about storms, tides, animals and plants. Additionally, with the use of an instrument recently developed by my lab group, I can make high-resolution measurements very close to the sediment-water interface. These results will help improve our understanding of the fundamental relationships that regulate beach dynamics.

Ripples through time

Sand ripples have been the subject of study for over a hundred years. In 1882, Arthur Hunt published his field observations on sand ripples and concluded that these ripples resulted from the oscillation of water back and forth over the sand. The following year, in laboratory experiments, Sir George H. Darwin injected ink into the water over a mound of sand. He concluded that water particles follow a swirling motion downstream from ripple crests. These pioneers in the field were studying what we now call vortex ripples.

These early observations were largely qualitative and it was not until 1946 that Ralph A. Bagnold designed an experiment to study vortex ripples in a more quantitative manner. In a large tank of water, he placed a layer of sand in a curved tray that swung back-and-forth in a circular arc. By allowing the sandy bottom to move instead of the water, Bagnold could better control the simulated wave action by modifying the motion of

Figure 1. A picture of sand ripples on a beach.

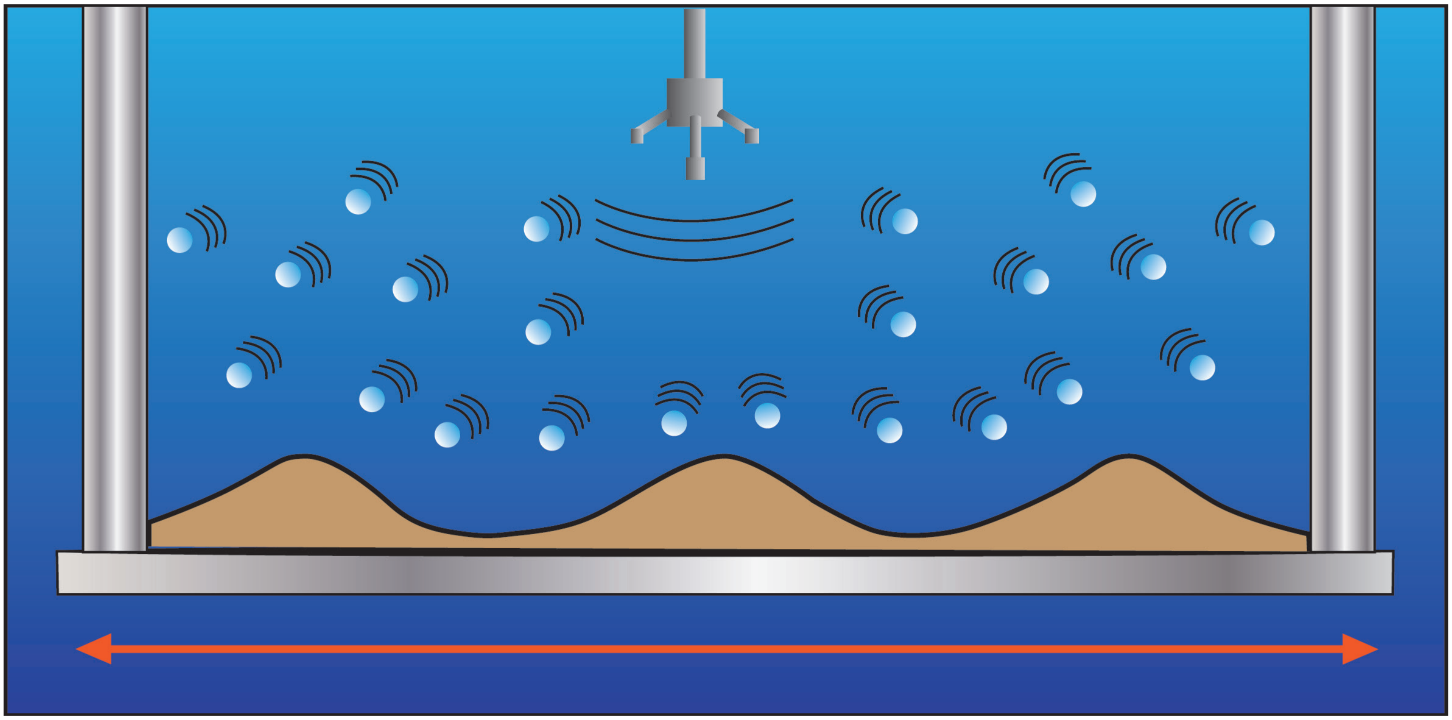


Figure 2. In our experimental set-up, a flat tray holding a layer of fine sand oscillates back and forth in a large tank of water. An acoustic instrument sends out pulses of sound that bounce off suspended particles in the water to measure the speed at which the water is moving.

the swinging tray. Using this ingenious set-up, he was able to quantify the relationship between ripple size and wave action. This led him to define vortex ripples as those having the distance between their crests (i.e. their wavelengths) proportional to the wave motion above them. Put simply, bigger waves will create bigger ripples.

Over the following decades, advances in measurement techniques allowed researchers to determine that as water flows over these ripples, vortices (eddies) are created downstream from the ripple crest. Since waves move back and forth, vortices are created on either side of the ripple crest giving ripples their somewhat triangular shape. Additionally, as the flow reverses direction, the vortex from one side of a ripple is swept back over the crest and is then ejected into the water column. Since vortices can trap sand grains, this process transports sand and thereby influences beach erosion.

Dalhousie Ocean Acoustics Laboratory

At any given time, the Dalhousie Ocean Acoustics Laboratory is bustling with activity. Several experiments that use acoustic technologies to study the interaction of sand and water motion are typically going on simultaneously. My current experiments on stationary ripples are inspired by the quantitative approach used by Bagnold in the 1940s; that is, a flat tray (2.4 m long by 0.8 m wide) holding a layer of fine sand (median grain size diameter of 153 microns) that oscillates back and forth (50 cm in 10 s) in a large tank of water (Figure 2). It takes about 10 hours to produce stable vortex ripples having a wavelength of 25 cm and a height of 5 cm (see Figure 3).

To measure the flow of water above sand ripples, it is important that the measuring instrument does not disturb either the flow near the bed or the shape of the bed itself. The instrument also has to be capable of measuring water motion in turbid (i.e. cloudy) waters, which rules out most optical techniques. To this end, our research group developed and built the Multi-Frequency Doppler Profiler (MFDop). This state-of-the-art instrument sends pulses of sound into the water and listens for the return signal (i.e. the echo), which provides information on both the shape of the sandy bed and the motion of the water. For the instrument to "see" well, the sound that it generates needs to bounce off of something in the water. To "help it out", we add fine particles of lime that remain suspended in the water and move with the flow. Tracking these suspended particles allows us to estimate their velocity, which shows how the water above the ripples is moving.

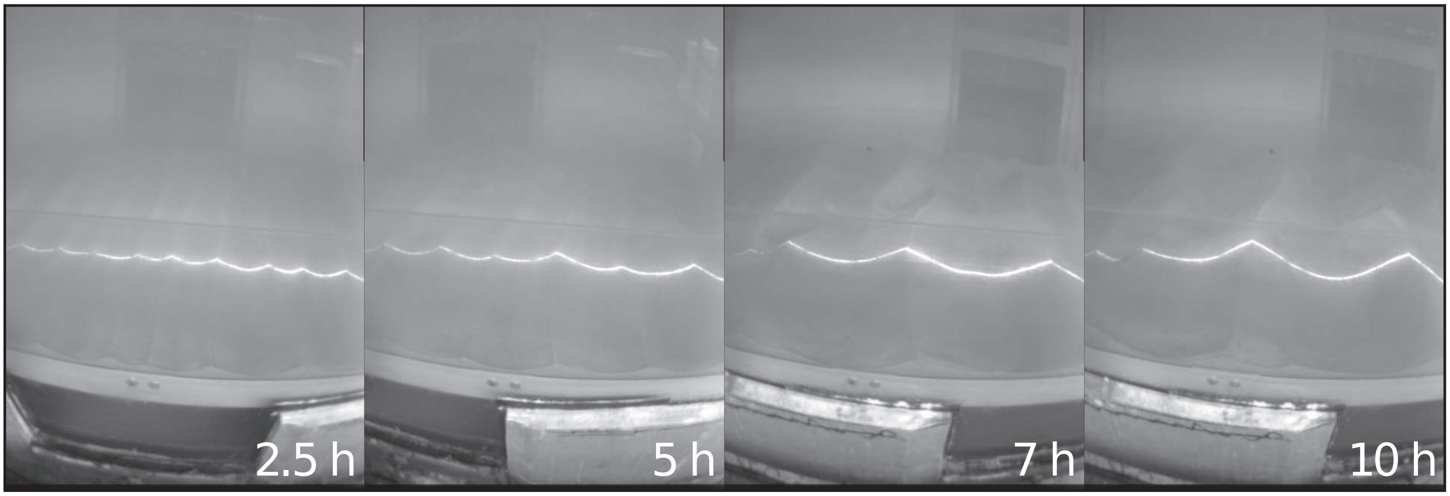


Figure 3. Ripple evolution. The bright line is a laser light sheet that helps to visualize the ripple profile.

A single experiment can take days or even weeks to complete. There are always adjustments to be made to the instrument's electronics, to the computers controlling the instrument or to the experimental set-up itself. Troubleshooting can take a long time and even when we get seemingly good data, we usually run the experiment more than once to verify that our results are repeatable. When we are satisfied with the results, we analyze the data in detail, which usually entails synchronizing data from different instruments, identifying and removing bad data points, as well as filtering out unwanted signals. This process can take days, weeks or even months depending on the type of data and the problems encountered.

Flow and turbulence over vortex ripples

My experiments have allowed me to reach two conclusions. First, the MFDop is capable of making accurate measurements very close to sand ripples (within 6 mm). Secondly, I have been able to confirm the existence of several known flow features of vortex ripples as predicted by theoretical models – that is, the acceleration of flow upstream from the ripple crest, its deceleration down the other side and flow intensification over the crest.

The results from one of my experimental trials are given in Figure 4. The flow field over one ripple is shown in the left-hand panel, where a vortex is beginning to take shape downstream of the ripple crest. In the right-hand panel, the energy associated with the rapid flow fluctuations (i.e. turbulence) is shown. A region of higher energy confined between the ripple crest and the trough is visible downstream of the ripple crest. High energy associated with the presence of the vortex is confined to a central core and decays outwards. Together, these high resolution measurements can be used to track the movement of the vortex over time.

I admit to being fascinated by this fine-scale view of things, but then I take a step back and reflect on how understanding the small-scale forces can help predict the large-scale processes that shape whole beaches and coastlines. Even though there is still much to be learned, the MFDop gives us both a better picture of what is happening very close to a rippled bed and a new-found capability of tracking vortices. These results are helping us to understand a small piece of the beach-dynamics puzzle.

One more thing…

Although we have made much progress in understanding near-bed flow, I have come to appreciate my supervisor's favourite expression: "there is just one more thing…". I have learned that the beauty of scientific research is that it never truly ends. More often than not, the answer to one research question raises more questions that require experimental modifications or further data exploration. Increasingly, I am the one asking the question that leads to investigating that "one more thing". Thus, since sand ripples in nature are not static, we are now interested in measuring the flow over evolving ripples. These results will help us to understand the influence of varying flow conditions on rippled beds. Invariably, these experiments will lead to exciting new discoveries that are likely to raise even more questions that need investigating.

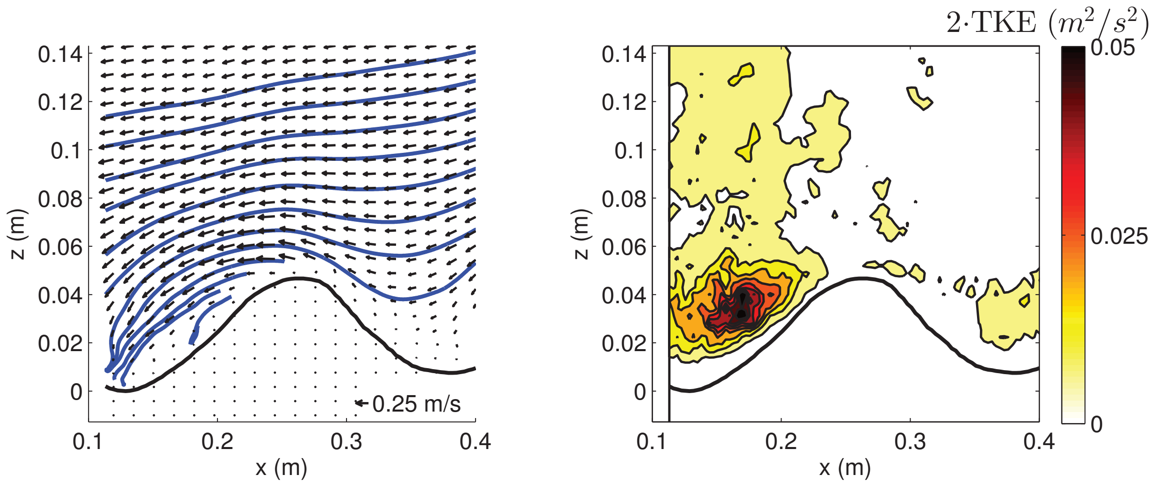


Figure 4. Left panel shows the flow field (arrows) and streamlines (blue) over a ripple. The black arrows represent the magnitude and direction of flow and the blue streamlines show the direction a water particle will travel. Right panel shows the energy of the rapid fluctuations in the flow over the ripple. The black line in both panels indicates the interface between the water and the sand.

Even now, the child in me is still mesmerized by the beautiful patterns that water creates in sand. Luckily, in the guise of an oceanography graduate student, I can spend my days playing with sand and water as I give my curiosity free rein to study the processes behind these mysteries of nature.

THIS WORK WAS FUNDED BY THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC) AND NORTEK SCIENTIFIC.

Jenna Hare

As a child, Jenna's fascination with nature led her to pursue studies in science so that she could understand how it all works. After completing an undergraduate degree in physics at Laval University, she moved to Halifax to pursue a master's degree in oceanography at Dalhousie University with Dr. Alex Hay. In doing so, she was able to apply the mathematical tools and physical concepts that she learned as an undergraduate to better understand beach dynamics. Her work on vortex ripples has encouraged her to continue doing research on coastal processes for her PhD at Dalhousie University. When she is not doing research, she can be found either playing team sports such as flag football or exploring the great outdoors by hiking and camping.

Finding Fresh Water

Using oxygen isotopes and salinity measurements to identify freshwater inputs to Bedford Basin

Elizabeth Kerrigan

Introduction

You drink it, you swim in it, and you bathe in it, but have you ever wondered where your water comes from?

With the increasing number of droughts around the world (e.g. California) and the addition of more fresh water into the ocean due to the melting of polar ice sheets (e.g. Greenland), it has never been more important to understand the sources of our fresh water. Changes to our supply of this precious resource will not only influence the water we consume on land – it will also affect the input of fresh water to the ocean, which could alter large scale processes such as ocean mixing and circulation patterns.

The potential impact of changes to freshwater inputs will be most significant in coastal communities, where proximity to the ocean defines culture, tourism, and industry. Halifax– where Dalhousie University is located, and where I live– is a maritime city on the east coast of Canada. Bedford Basin is the largest region of Halifax Harbour (Figure 1) and receives offshore water from the Scotian Shelf. In the future, increased sea-ice and ice sheet melt entering the North Atlantic Ocean may alter the freshwater composition of the Scotian Shelf. It is therefore essential to understand the current composition of the water in Bedford Basin, so that future changes can be monitored and quantified. To establish this baseline and, hence determine where the fresh water in Bedford Basin has originated from, I am studying the water molecules themselves (i.e. H_2O).

The Water Cycle and Oxygen Isotopes

Before I explain how I can distinguish one water molecule from another, let me first remind you of the water cycle – that relatively simple cycle that you first learned about in

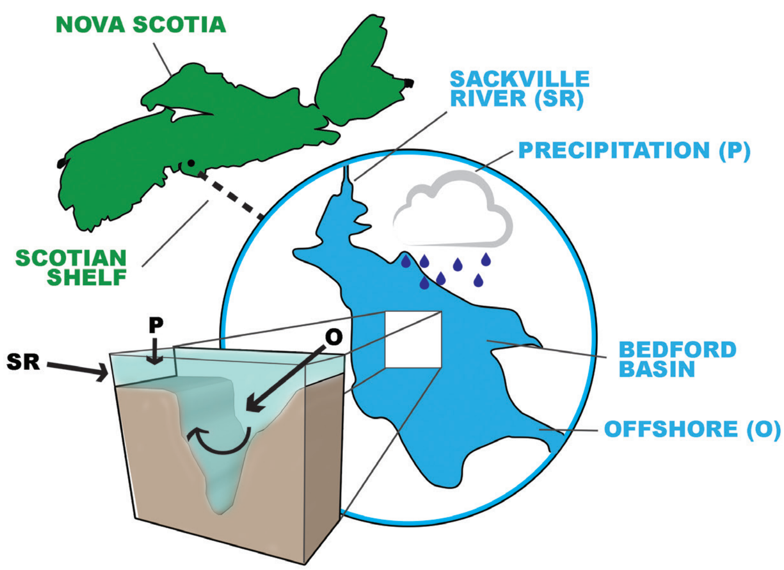


Figure 1. Bedford Basin, and its position with respect to Nova Scotia and the Scotian Shelf. The three major inputs to Bedford Basin (Sackville River, precipitation, and offshore) are identified, with a vertical depth profile illustrating the general circulation of these inputs in the surface and deep waters of Bedford Basin.

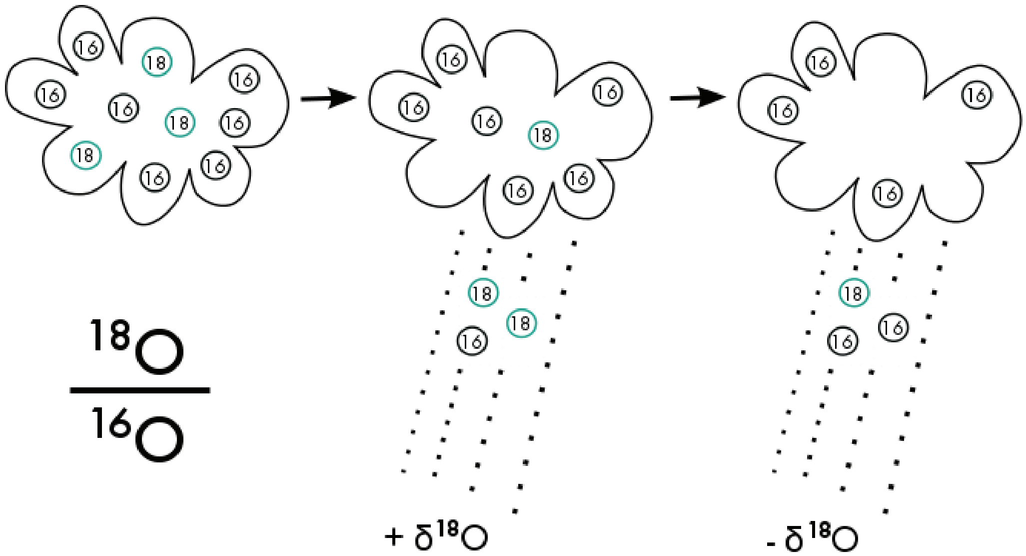


Figure 2. Schematic of isotope partitioning of ^{16}O and ^{18}O in clouds during rainfall. Note: $\delta^{18}O$ is a measure of the ^{18}O:^{16}O ratio where the neutral value (i.e. zero) is determined from a standard and typically rainfall is isotopically depleted (negative $\delta^{18}O$)

elementary school – which is responsible for the movement of fresh water around the earth. Water is first evaporated from the surface ocean, leaving behind its salt. As the water vapour rises into the atmosphere, it cools and condenses to form clouds. Once these clouds are supersaturated (i.e. can't hold any more water), we get rain (or snow). All of this water will eventually make its way back to the ocean as rainfall, river runoff, or glacial ice-melt (that has been storing this water for thousands of years).

Don't worry, you weren't misled in elementary school – all water is composed of H_2O molecules; but, we can

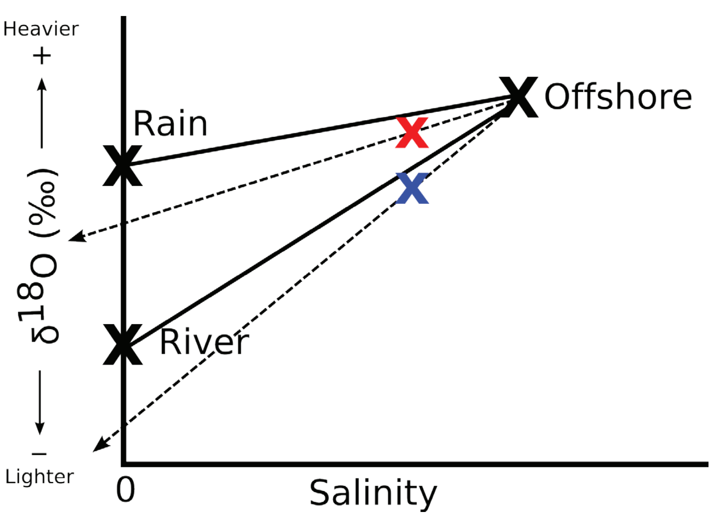


Figure 3. Schematic of a $\delta^{18}O$ mixing triangle with rain, river and offshore end members (black "x") along with potential water samples (red and blue "x")

differentiate between water molecules by examining the oxygen (O) atoms. All water molecules include one oxygen atom, but these atoms can be composed of either 8 protons and 8 neutrons (^{16}O), or occasionally, 8 protons and 10 neutrons (^{18}O), leading to atoms with differing atomic weights (^{16}O is lighter than ^{18}O). These variants of the same element (i.e. the same number of protons, but varying neutrons) are called isotopes and the differences in mass cause water molecules to react differently in the water cycle. When water is evaporated, more of the lighter isotopes are picked up first, leaving more of the heavier isotopes in the ocean, resulting in an imbalance of ^{16}O and ^{18}O both in the clouds (more ^{16}O) and in the ocean (more ^{18}O). Similarly, as rainout occurs, the heavier isotopes (^{18}O) are progressively released as precipitation, while more of the lighter isotopes are left in the clouds, meaning that each progressive rainout is lighter, leading to an increased surplus in ^{16}O, as shown in Figure 2.

This process of isotopic fractionation means that different ratios of ^{16}O and ^{18}O are found in various parts of the water cycle. We quantify these isotopes using the $\delta^{18}O$ parameter, which is the ratio of oxygen isotopes (^{18}O:^{16}O) compared to a standard with a known ratio. Put simply, a sample with more ^{18}O (relative to the standard) will have a positive $\delta^{18}O$ value, while a sample with more ^{16}O will have a negative $\delta^{18}O$ value. This means that variations of ^{16}O and ^{18}O in the water cycle can help us determine where water has originated. For example, ice in the Arctic will be composed of more light (^{16}O) water molecules ($\delta^{18}O$ near -40‰), than rain in Halifax ($\delta^{18}O$ near -6‰).

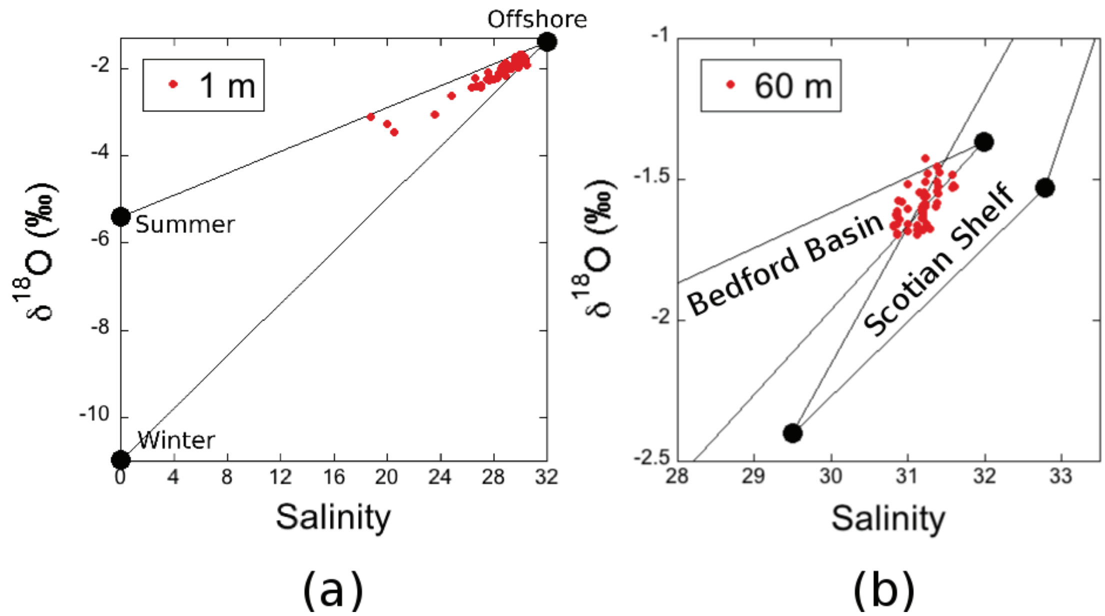


Figure 4. Bedford Basin (a) 1 m and (b) 60 m samples collected from June 2012 to October 2013, with their fit in the Bedford Basin mixing triangle, (b) also identifies the samples that fall in the Scotian Shelf mixing triangle at 60 m depth

Mixing Triangles

In oceanography we often use "tracers" to determine where water sources originate and how this water circulates. One commonly used tracer is salinity; or, the salt content of water. In areas of high evaporation (e.g. Equator) salinity is high (~35 psu), whereas areas with a high freshwater input (e.g. Arctic) have lower salinities (~30 psu). Although salinity can be a useful tracer in the ocean, it cannot distinguish between different freshwater sources (i.e. rainfall vs. river runoff). In Halifax Harbour, where multiple inputs of fresh water are present, we can pair $\delta^{18}O$ and salinity to determine unique characteristics for each source.

An "end member" is a specific water mass with a known $\delta^{18}O$ and salinity value, such as "River", "Rain", and "Offshore" in Figure 3. By looking at where a water sample falls on this "end member mixing triangle" we can determine the relative proportions of each source (i.e. the sample's composition). For example, in Figure 3 the "red" sample falls within this mixing triangle and is therefore composed of these three end members. The y-intercept of the red sample line (dashed) can be used to determine the $\delta^{18}O$ of the freshwater input to the sample, showing that this input must be a mixture of rain and river water. The "blue" sample, in comparison, falls outside the mixing triangle so there must be a different freshwater end member driving its composition. By looking at where the regression line crosses a salinity of zero, an isotopically lighter (- $\delta^{18}O$) freshwater input (i.e. a source other than the pre-determined end members) must be present in this sample, causing it to fall below the mixing triangle. So, by establishing end members from possible sources, we can see if the sampled water fits into the mixing triangle. If it does, then the relative ratios of the water sources can be determined, whereas if the sample lies outside the triangle, there may be other water sources present.

Establishing Bedford Basin End Members

Bedford Basin has three main inputs: two freshwater (precipitation and Sackville River), and one saltwater input of offshore water (Scotian Shelf). To establish the possible end members for my water samples, I first measured the $\delta^{18}O$ and salinity of these inputs. I collected precipitation samples in a large container during every rain (or snow) event on the roof of my office building, giving us a complete picture of the variability in $\delta^{18}O$ throughout the year in Halifax (June 2012 – October 2013). I also collected Sackville River samples once a month by lowering a bucket off a small pedestrian bridge. Offshore samples were collected from the Scotian Shelf on two four-week long ocean research cruises on the CCGS Hudson (October 2008 & April 2009).

Unfortunately, the $\delta^{18}O$ of the Sackville River and precipitation inputs could not be distinguished from one another, as the $\delta^{18}O$ of these inputs co-varied throughout the year, showing the same seasonal trends. This is because the precipitation drives the isotopic composition of lakes and rivers around Halifax, and hence the two freshwater sources are directly related. However, because of the large range in the $\delta^{18}O$ of precipitation throughout the year (-3 to -30‰), we could use summer and winter precipitation to define our freshwater end members (-5.39 and -10.97‰ respectively). We could then determine the composition of water in Bedford Basin from these three end members (summer precipitation, winter precipitation, and offshore water).

Results & Why?

Bedford Basin is a deep basin (71 m), in an otherwise shallow harbour (10 – 20 m). Heavy, salty water from offshore moves along the bottom of the harbour ending up in the deep waters of Bedford Basin, while surface waters become fresher and lighter with the input of sewage runoff, river water, and precipitation. The deep waters of Bedford Basin are, therefore, often stagnant with little to no input of fresh water from the surface during the year.

Because of the differences in the surface and deep waters in the basin, I chose to collect water samples from both 1m and 60 m depth. For each sample, I measured the $\delta^{18}O$ and salinity and plotted the points on my mixing triangle (Figure 4) to try to determine the primary sources. At the surface, I found that the majority of the water is composed of offshore water (~90%), with a mix of fresh water (~10%) entering throughout the year (Figure 4a). However, when this analysis was performed on deep Bedford Basin waters, a number of samples fell outside the mixing triangle (Figure 4b), suggesting that there is an additional, isotopically lighter (- $\delta^{18}O$), input of fresh water that is not originating from a local source (i.e. the measured rain, river or sewage). As such, when these samples fall below the mixing triangle (and into a Scotian Shelf mixing triangle), Bedford Basin deep waters are composed solely of ocean water that never interacts with fresh water input from the Halifax region. In this case, the $\delta^{18}O$ of fresh water (identified using the zero-salinity intercept) actually represents the fresh water present on the Scotian Shelf, where the source is much further away (i.e. St. Lawrence River and Arctic river water).

Based on my analysis, it is evident that regardless of depth, incoming offshore water makes up the majority of water in Bedford Basin. At the surface, there is a minimal input of fresh water from land, however these inputs – primarily from rain and river outflow – rarely reach the deep waters. This leads to an exciting conclusion – by examining the $\delta^{18}O$ of fresh water at 60 m depth we can actually monitor the freshwater balance on the Scotian Shelf. This means that by studying the deep waters of Bedford Basin it may be possible to examine changes in offshore waters caused by increased Arctic river flow or ice melt from the North Atlantic. The establishment of this baseline mixing triangle is critical to the interpretation and quantification of these future changes. As such, we will be able to monitor the freshwater inputs to Bedford Basin, allowing us to protect and preserve this natural harbour which is central to the tourism, economy, and culture of Nova Scotia.

THIS RESEARCH WAS FUNDED BY THE CANADA EXCELLENCE RESEARCH CHAIRS PROGRAM.

Elizabeth Kerrigan

Originally from Saint John, New Brunswick, located on the world famous Bay of Fundy, Elizabeth grew up with a love of the oceans. Although she first got hooked on the oceans through "The Little Mermaid", she actually became interested in ocean science after a marine biology summer camp at the Huntsman Marine Science Centre at the age of 9. After completing a BSc at Mount Allison University in Environmental Science, she left the mudflats of the Tantramar Marsh and headed toward the coast of Nova Scotia to begin an MSc in Oceanography at Dalhousie University. In addition to her love of the ocean, Elizabeth is an avid synchronized swimmer who likes to spend her free time reading books or watching movies, curled up with a cup of tea.
Photo Credit: Jay Mar Quevedo

Echoes from Frozen Muddy Waters

Using an echosounder to detect sunken sediment-laden ice

Nicholas Dourado

There is some power in them tides.

I never aspired to be an astronaut, scientist, or oceanographer as a kid. I certainly had the imagination and curiosity for such a career, but my limited ambition rarely caused me to explore beyond my own neighbourhood. So, I was surprised to find myself in the roaring silence of the open seas. The sheer vastness and mystery of the ocean has brought me – a junior environmental scientist – in tune with the courageous explorers of yesteryear.

Outside of our bustling, organized cities await the keys to many of society's technical challenges. For example, out at sea, the ocean surface heaves up and down, following the journeys of the moon and the sun around the planet. This motion generates a large-scale flow of water; i.e. the tides. As the ocean surface rises and falls, water is forced into narrow channels where the power in the tidal current can be significant. An example of this is in the Bay of Fundy, where the sea surface height varies by as much as 16 metres. This tidal range, which is the largest in the world, produces exceptionally strong currents. The energy in the flow can potentially be converted to electricity using tidal turbines, and a recently proposed installation in the Bay of Fundy's Minas Passage has been a cause for much excitement. These turbines represent an enormous investment, since they are expensive to build, install, and repair. However, the payoff is irresistible; harvesting energy from some of the world's most powerful currents could satisfy the energy needs of coastal communities, easing their reliance on fossil fuels for power.

Who cares about some muddy ice?

My adventure as a physical oceanographer began during a frigid maritime winter, in the Bay of Fundy's treacherous ice fields. As the tides recede, they reveal vast, desolate tidal flats, resembling an almost extra-terrestrial environment. Enormous weeping boulders of mud and ice appear to have fallen from the sky (Figure 1), littering the horizon. At low tide, the tidal flats appear quiet and still, but the muddy ice debris tells another story. These icy boulders are formed along the banks of tidal rivers that transform from soft mud slides into multi-story ice cliffs as winter arrives (Figure 2). When these ice cliffs break down, the mighty tidal currents carry the large ice blocks down the river, where they are rafted out into the bay. They will melt eventually, but the final destinations of these ice blocks are still unknown. Part of the uncertainty is driven by evidence that suggests that muddy ice blocks can sink, due to the encased rocks and mud. This has led to concerns that they could collide with underwater tidal turbines, and thus reduce the turbines to mangled wrecks of metal. It is not practical to guard the turbines underwater, so we need some way to locate and identify sunken muddy ice remotely.

Figure 1. Mud and ice combine on the tidal flats in the Bay of Fundy, leaving behind dense, towering ice sculptures.

Figure 2. Ice cliffs that form along tidal rivers can grow as high as 5 metres before they collapse, spilling muddy ice into the river.

The sound of science.

Our eyesight is a valuable tool in our atmosphere, however, since light does not penetrate the turbid water in the Bay of Fundy, our normal ability to see is impaired. Fortunately, sound can travel much longer distances than light in water, so oceanographers can rely on their ears, instead of their eyes, to probe the deep. Sound is something we learn to take for granted. We are so inundated with noise in our environments that we miss the opportunity to examine the structure and regularity of the sounds around us. Sounds are the evidence of motion spread across space and time. The physics of sound reveal that our soundscape is the result of elastic waves moving through matter, which could be air, water, buildings, our skulls, or muddy ice blocks.

Not surprisingly, humans are not the first marine mammals to use echoes to locate objects underwater. You may be familiar with dolphins, who use echolocation to gain the upperhand on their prey. If a sound is broadcast, the time it takes for the echo to return can provide an accurate measure of the distance the sound had to travel. The first device developed for this task, the Fessenden oscillator, was an echosounder used to locate icebergs at sea. It was invented in light of the tragic sinking of the RMS Titanic, which was a sobering reminder of the hazardous strength of ice.

While there is no doubt that an echosounder could locate an underwater ice block, the remaining uncertainty that needs to be resolved is the strength of the ice blocks. After all, if the ice is brittle, a turbine may be able to tolerate a collision. Since the strength of an ice block is likely related to its internal structure, we need some way to look (or, in this case, hear) into the ice. If a sound pulse passes through the surface of the ice, the returning echo may contain evidence of the sediment or air bubbles contained inside. The question now becomes, can a sound pulse really penetrate the surface of an ice block? If so, are echoes from inside the ice strong enough to be identified? More than that, what do rocks and air bubbles in ice blocks even sound like?

The problem of predicting echoes has some surprisingly elegant solutions. Discovered in part by Lord Rayleigh in the 19th Century, special functions are used to account for the shape and material properties of an object, as well as the properties of the transmitted sound. These solutions, however, are most accurate for single objects with simple shapes. Since muddy ice blocks come in all

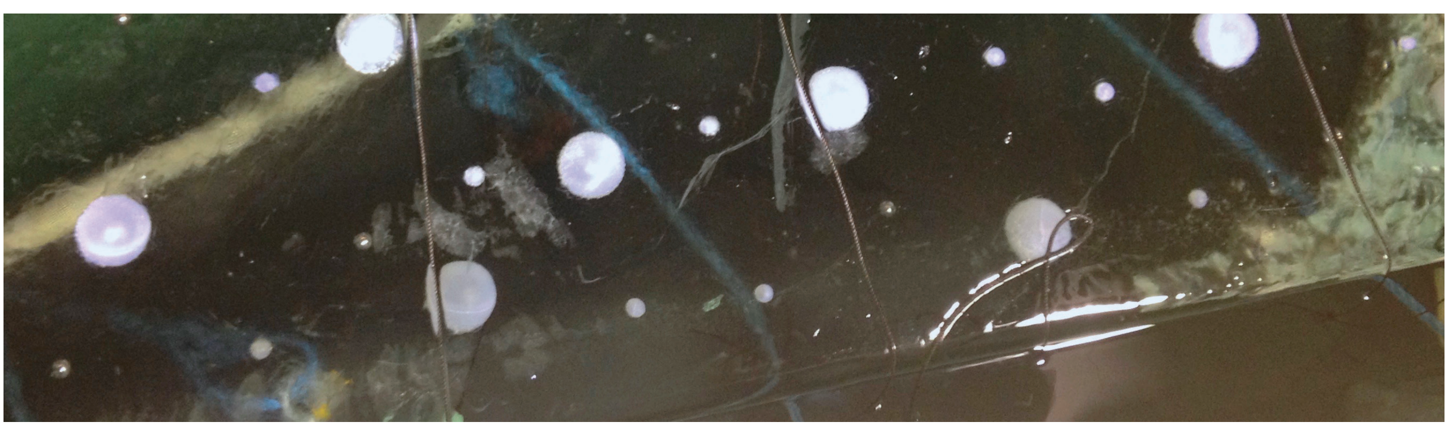


Figure 3. Target spheres were frozen in bubble-free ice blocks in an attempt to identify solid and hollow inclusions in ice using an echosounder.

shapes, sizes and compositions, the problem of predicting echoes from them is not straightforward. Fortunately, certain approximations can simplify this problem and we can piggy-back on the previous work of ocean scientists who use echosounders to detect fish. The air trapped in the bladders of many fish species can be modelled as large bubbles which produce strong echoes, allowing them to be detected with echosounders. Now, the simpler question becomes: is it possible that air cavities trapped inside ice blocks could also provide such a strong signal?

To the Lab!

Simulating echoes from complex muddy ice blocks would be a monumental task, since the echo depends on the size, shape, and composition of the ice block, all of which are variable and difficult to measure. In order to test the theory that sound can be used underwater to probe the inside of ice, I needed to reduce the complexity of the problem. With the help of an ice sculptor, I was able to freeze solid and hollow spheres inside huge bubble-free blocks of ice (1 m by ½ m by ¼ m). My ice sculptures were perfectly rectangular on all sides, with smooth faces and target spheres frozen in

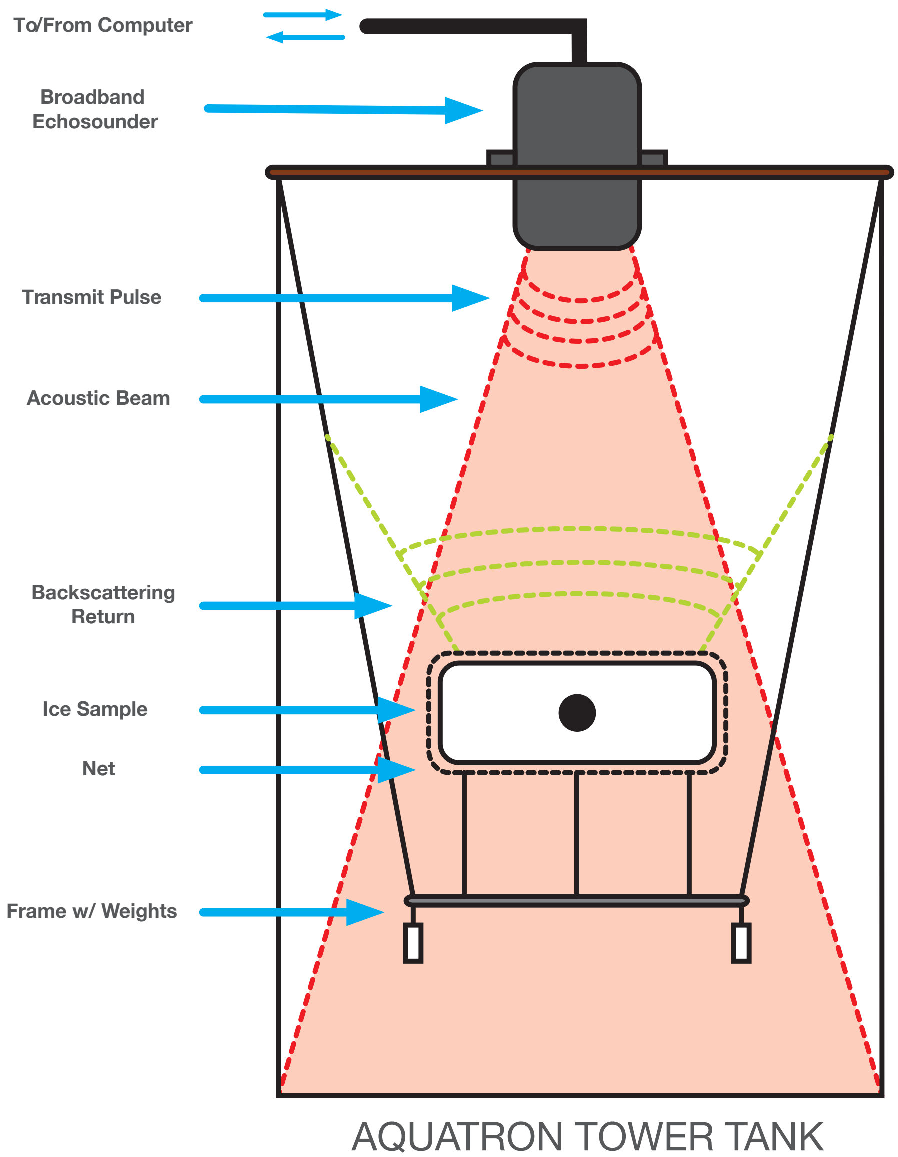


Figure 4. An echosounder bounces sound pulses off bubble-free ice blocks held underwater. I recorded the sound reflected from the blocks and searched for evidence of the spheres frozen in the ice.

the centre (Figure 3). I was able, with much help, to secure these blocks underwater in the Aquatron Tower Tank (a ten-metre tall tank filled with seawater and the occasional sea turtle) at Dalhousie University. Using a broadband echosounder system, I sent a sound pulse into the water and recorded the echoes from the ice as it melted within the tank (Figure 4). Not surprisingly, echoes from target spheres in water only (i.e. no ice) show an excellent agreement with modelled predictions, which means that our echosounder was properly calibrated. But what about in ice? Can we predict and measure the presence of the spheres?

Cracks in the ice.

The dynamic and impermanent nature of ice makes it a truly frustrating lab partner. Unfortunately, I didn't learn my lesson as a kid when a few of my precious ice cubes cracked as they melted in my lemonade. In the tank, cracks formed along the surface and extended throughout my ice blocks, making it very difficult to separate the measured echoes from the ice surface, cracks, or target spheres. My observations from uncracked ice showed strong echoes from the top and bottom of the ice surfaces, which implied that sound can, in fact, penetrate a smooth, planar ice surface. Much to my horror, however, no evidence of the encased target spheres could be identified in these echoes. How could it be? It turns out that on top of supporting the dominant compressional (i.e. "squishy"), sound waves, solid objects can also support waves that twist and bend. These surface waves traveled along the surface of the ice blocks, much like a wave upon the ocean, and generated extra sounds that masked the echoes from the encased targets.

My experiments left me with the bitter taste of defeat. Since I was unable to observe echoes from large spheres in ice, how could I possibly detect tiny air bubbles and sediment particles? My goal of remotely estimating ice block strength seemed out of reach. Although this was not the result I had hoped for, I was able to compare the echoes from both cracked and solid ice surfaces, and found that the surfaces of cracked ice blocks scattered much less energy! Since cracks at the surface of ice seem to imply fractures within the blocks, the strength of the surface reflections may provide a reliable means of estimating ice strength, if not its actual composition. This means that perhaps listening to the echo from the surface of muddy ice blocks could still be a useful monitoring tool for tidal turbines.

The Bay of Fundy means so much to so many. At times, a quiet place for tradition and reflection, and other times a wild, energetic environment that is home to a patchwork of organisms and surprisingly unique phenomena. As the winter draws to a close, the muddy ice orchestra clamours through the tidal rivers into the forever mysterious bay and it is hard to imagine what else could be concealed by the turbid, noisy tidal currents. Nevertheless, as long as turbines are to operate in the precarious Bay of Fundy, I suggest that someone keep on the look out, with their ear to the sea.

THIS RESEARCH WAS FUNDED BY NOVA SCOTIA POWER INC. AND THE NOVA SCOTIA DEPARTMENT OF ENERGY PENGROWTH ENERGY INNOVATION GRANT.

Nicholas Dourado

Nicholas Dourado is part mascot, mover, wavewatcher, engineer, oceanographer and loudspeaker. He prefers to solve problems with sound but would deny that this has to do with a childish obsession with harmony. When he can sit still, he looks at something until it's worth it and that will take longer than expected. His adventures have sent him to the ocean and beyond, where he is believed to have discovered paradise. He is susceptible to hyperbole and is grateful for those who tell it like it is. Nicholas probably wants to hear from you. He would prefer to hang out and chat instead of doing his work, he will surely prevail with both.

Shedding Light on the Seafloor

Using optical imagery to study deep-sea benthic communities

Myriam Lacharité

'Hotspots' on the deep seafloor

In the depths of the ocean, hundreds of metres below the surface and far off the familiar coast, lie fascinating 'hotspots' of abundant and diverse life forms. There, the cold darkness hides a rich community of colourful organisms such as corals, sponges, sea stars, and anemones. These organisms thrive in habitats with fast sweeping currents that bring food from the surface ocean, disperse early life stages to new habitats, and keep bedrock and boulders free of sand. These conditions allow for colonization, and this reliance on current regimes causes these key ecological areas to be mostly found in areas of steep bathymetry, where the shape of the seafloor changes dramatically. More specifically, these diverse communities are typically located on ridges and basins on continental shelves, submarine canyons off continental margins, and seamounts.

The old-age, typical slow growth, and erect morphology of these organisms render them vulnerable to disturbances such as destructive fishing practices. How coral ecosystems influence the distribution of bottom-dwelling fish is an ongoing topic of research, but it has been shown that fish do use these habitats as shelter from predation. Most of these ecosystems have hence long been considered as attractive fishing spots by fishermen and large corals were often – and still are – caught as bycatch in nets. For scientists and marine managers alike, describing the distribution of these ecosystems and the rich diversity of their inhabitants is essential to establish sound management plans to avoid further destruction. However, until recently, scientists had few means to examine these fragile ecosystems because studying the seafloor of the deep ocean is both expensive and logistically difficult.

Optical imagery of the seafloor

New tools have arisen to study in-situ these ecosystems while minimizing the disturbance to the seafloor. Remotely-operated vehicles (ROVs) and automated underwater vehicles (AUVs) – i.e. underwater robots – are equipped with high-resolution video cameras, photographic cameras, and mechanical arms lending to precise manipulation of instruments on the seafloor. This allows us to discover new 'hotspots', describe the distribution of these deep communities, and study ecological processes affecting their life cycle. For my graduate research, I am

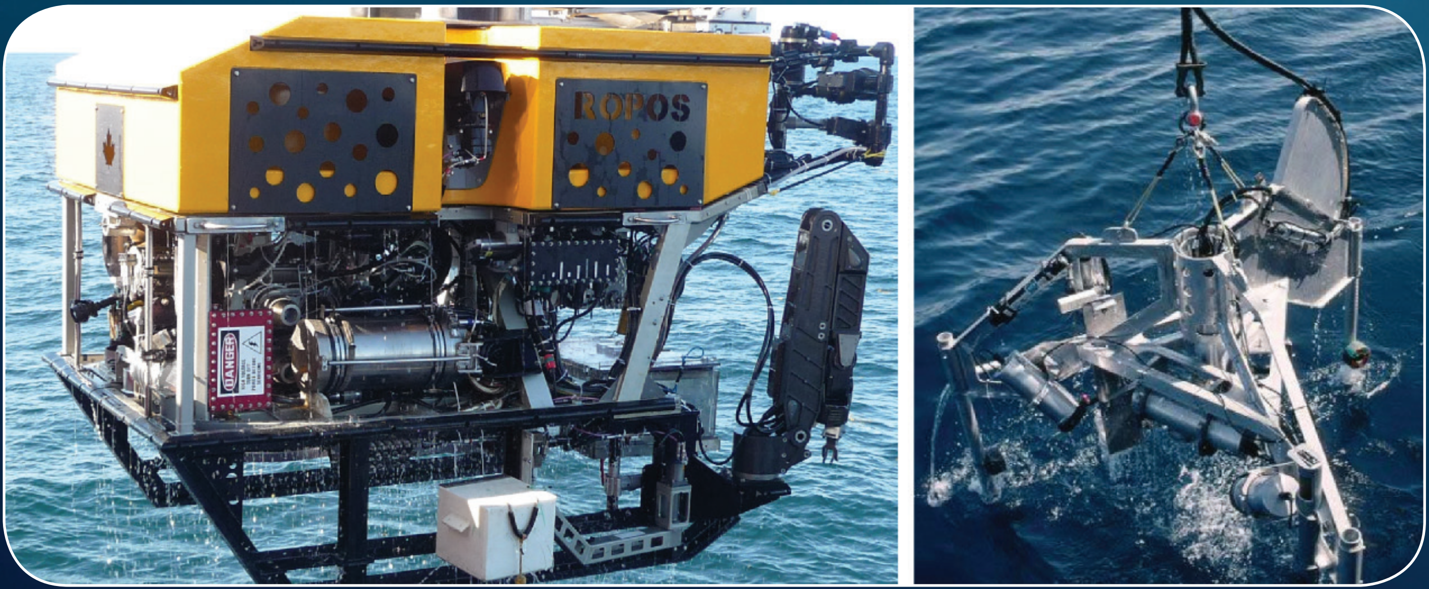


Figure 1. Left: Remotely-operated vehicle ROPOS (operated by the Canadian Scientific Submersible Facility). Right: Campod (Photo credit: Fisheries and Oceans Canada).

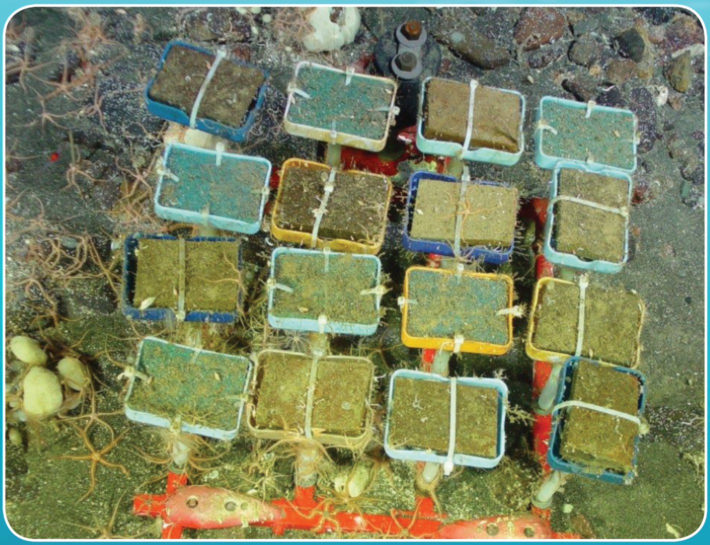


Figure 2. Array of larval settlement units deployed in the Middle Canyon (Gulf of Maine), 658 m. Photo credit: Canadian Scientific Submersible Facility.

examining the distribution and factors influencing communities of fauna itn the deep waters of the Gulf of Maine and adjacent continental margin (Northwest Atlantic) using information collected by the ROV called ROPOS (operated by the Canadian Submersible Scientific Facility) and the towed-camera called Campod (operated by Fisheries and Oceans Canada) that are shown in Figure 1.

Ecological factors affecting deep-sea benthic communities

The deep seafloor of the Gulf of Maine harbours a rich fauna of cold-water corals, most notorious amongst them the bubblegum coral *(Paragorgia arborea)* and seacorn coral *(Primnoa resedaeformis)*, for which a coral conservation area was established in 2002. A portion of my research used a field experiment, where we deployed colonization plates at great depths (> 600 m) over a period of 4 years to study recruitment of these corals in the coral conservation area (Figure 2). Our findings supported the currently-held view that these corals are vulnerable to disturbances since their ability to establish themselves in new habitats (or re-colonize disturbed habitats) appears limited.

How important the physical environment (e.g. depth, currents) is on influencing the presence and abundance of deep-sea biological communities is an ongoing topic of research. A more precise description of the relationship between these organisms and the environment would allow scientists to use information about the physical environment to predict the occurrence of these ecosystems in habitats that have not yet been sampled. My research compares the distribution of these communities in different regions of the Gulf of Maine – contrasting basins, channels, and canyons – with environmental patterns at multiple spatial scales: from the immediate vicinity of the community (a neighborhood of meters) to the environment in the region as a whole (a neighborhood of 10's of kilometers). This is meant to reveal how tight this relationship is, and at which spatial scale it is strongest.

To describe the physical environment in which these communities thrive, I combine characteristics of the shape of the seafloor, the composition of the sediment, and dynamics of the overlying water column. Since most of these communities ultimately rely on food sinking from the surface, their presence on the seafloor is most probable where strong currents prevail. Steep bathymetry at varying spatial scales can influence how swiftly currents flow close to the bottom. The interaction of flow with the bottom, either as friction or the presence of large boulders, can produce turbulence, which is also thought to contribute to higher feeding rates. Considering all these factors together can help scientists determine an optimal range of environmental conditions in which you find this fauna. In my research in the Gulf of Maine, I use available depth measurements obtained from high-resolution multibeam echosounder surveys coupled with modelled bathymetry to determine the shape of the seafloor, state-of-the-art ocean circulation models to determine water characteristics, and in situ samples combined with optical imagery (pictures and videos) to determine the composition of the sediment.

Quick & efficient processing of seafloor imagery

Optical imagery of the seafloor allows scientists to have a much closer look at the abundant, diverse, and colourful communities in deep waters (Figure 3), as well as the underlying sediment

Figure 3. Optical imagery of the seafloor captured by Campod (operated by Fisheries and Oceans Canada). Jordan Basin (Gulf of Maine), 133 m.

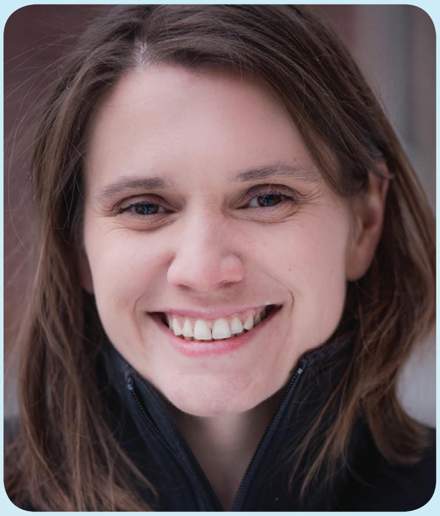
composition. However, imagery remains a challenging tool to use, since many factors – including luminosity, view angle, and distance from the seafloor – influence the detection and identification of organisms. This leads to biases due to our tools, but also due to the human observers processing this imagery. Such imagery can also easily translate into hours of video and/or thousands to hundreds of thousands of pictures, which burdens and slows down the course of scientific research. Because of these factors, I have developed an automated way to process optical imagery based on principles of computer vision. The goal of the approach is to decompose an image into a multitude of 'image-objects', regions of the picture where colour and luminosity are homogeneous. This approach has been used with satellite remote sensing on land – to discern cities from forests, for example – but its application to determine seafloor properties is still in its infancy. Instead of mapping cities and forests, my approach aims to estimate the composition of the sediment on the seafloor, and distinguish life from the mud, sand, and pebbles.

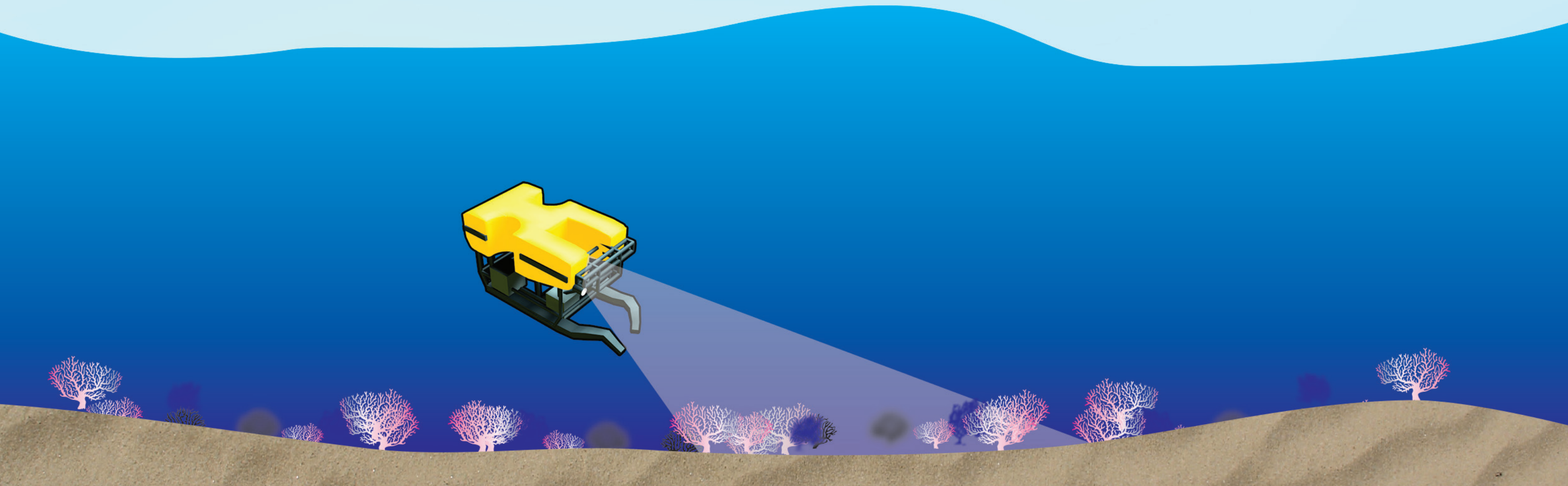
Overall, my research brings together principles of ecological theory, high technology, and the development of new efficient ways to use this technology to both describe and understand the factors influencing the composition and distribution of bottom fauna in deep waters. This is meant both to advance scientific knowledge and inform management decisions to preserve these rich ecosystems.

THIS RESEARCH WAS FUNDED BY FISHERIES AND OCEANS CANADA, THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC) AND AN IZAAK WALTON KILLAM PRE-DOCTORAL SCHOLARSHIP.

Myriam Lacharité

Myriam grew up near Montréal (Québec) on the shore of the St. Lawrence River. As an undergraduate student at McGill University in biology, her interest in aquatic ecology was focused on fresh-water ecosystems. During her final year, she had the opportunity to hop on a research cruise in the Estuary of the St. Lawrence, where she discovered the rich biodiversity living on the seafloor. She then decided to transition to marine systems, and came to Dalhousie University to pursue a PhD in biological oceanography under the supervision of Dr. Anna Metaxas. She is now interested in mathematical ecology, and how best to represent relationships between biological patterns and environmental drivers, especially in marine systems. In her spare time, she likes to play with computer languages, develop her keen interest in environmental issues, and stay active by enjoying a good run or a hike up a steep mountain.





Thank You

As Editor-in-Chief of Volume 2 of *Current Tides*, I want to extend a HUGE thank you to both the authors and the editors (pictured below) who put in countless hours of hard work over the past year. When they agreed to contribute to this edition, I doubt they anticipated either the number of revisions I would ask of them or the number of annoyingly long emails they would receive from me. But together, we persevered and I am very proud of both the quality of the articles and the research they describe. The magazine is far from perfect – but it is ours!

A sincere thanks must also be extended to Franziska Broell who dreamed up the idea of *Current Tides* and worked tirelessly to produce the first edition in 2013. Her guidance throughout the production of Volume 2 has been crucial to both my sanity and the overall success of this endeavor. The persistence and perseverance of our graphic designer, James Gaudet, is also much appreciated as he completed numerous rounds of edits and never complained about my nitpicky comments regarding subscripts, italics or white space (among other things).

And finally, *Current Tides* greatly benefits from the support and encouragement provided by members of the Dalhousie Oceanography Students Association (DOSA) and the Department of Oceanography. Your collective excitement to read and promote the magazine has provided ample motivation to complete this ambitious task.

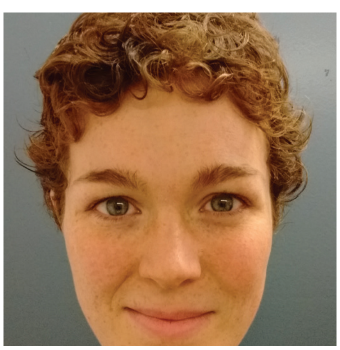
- Justine

Justine McMillan
Tides & Turbulence

Jonathan Izett
River Plume Transport

Andrea Moore
Invasions & Global Change

Anne McKee
Lobster Habitat Mapping



Gennavieve Ruckdeschel
Acoustics & Zooplankton

Krysten Rutherford
Shelf Carbon Dynamics

Lorenza Raimondi
Air-sea exchange of CO_2 *&* O_2

Jean-Pierre Auclair
Wave & Ice Dynamics

Current Tides

Current Tides Magazine, Dalhousie University
Department of Oceanography, Halifax, B3H 4R2

Sponsored By

Dalhousie University
Inspiring Minds
Faculty of Graduate Studies

Dalhousie Student Union

Dalhousie Oceanography

Tandem creative

MEOPAR
Marine Environmental Observation Prediction & Response Network