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**Cover photo credit:** The monument celebrating "The MI'KMAQ Cultural Landscape at Kejimkujik", at Kejimkujik National Park and National Historic Site, Nova Scotia (Peter Wells).

**Back cover inset photo credits:** Top: Lichen, the Tree Lungwort *Lobaria pulmonaria*, on a tree trunk; Centre Left: Impression of a petroglyph found on the lakeside rocks at Kejimkujik National Park; Centre Right: A birch bark canoe being built by a MI'KMAQ elder; Bottom: Eastern American Toad, *Anaxyrus americanus*,on the forest floor (all photos taken at Kejimkujik National Park, July 8th, 2023, by Peter Wells).

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**Editorial**



**Commentaries**



**Research Articles**



*Continued*

Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 1-4

# EDITORIAL

## Living in a global environmental emergency ward – the need to address problems with science, action and speed

Welcome to the new Issue of the PNSIS. This piece is being written at the end of the summer, midway through another hurricane season in the Maritimes and this one purported to be noteworthy. So far, three storms have barreled up the Atlantic coast, with post-tropical storm Lee hitting us directly and with more predicted to come. This follows several months of unsettled weather, resulting in Nova Scotia being marred by wildfires, excessive rain, unusual and tragic flooding, and a slow recovery from last years, massive subtropical storm Fiona. Wildfires continue in Quebec and out west in Alberta, BC and the NWT, causing people to evacuate and resulting in enormous loss of forests, homes and other community infrastructure. It has made Canadians across the country, especially residents of Nova Scotia, much more aware of extreme weather events and the changing climate, and wondering what the future holds for their descendants.

During times of reflection about such issues, the environment in general, and with my head in an excellent autobiography penned by a distinguished environmental biologist (Ehrlich 2023), it appears as though we are currently living in an environmental emergency ward, the patients (forests, waters, coastal and ocean ecosystems, wildlife, our homes and communities, us!) coming in faster than they can be diagnosed, stabilized and treated. Although the gravity of these events may be accentuated by the 24 hour news cycle, it is clear that the problems we face are real, serious and a bit overwhelming.

Throughout much of my career as a marine environmental scientist, I have felt that based on the facts, humanity is in a dire environmental situation. This was predicted by some but until recently, not generally recognized. My first wake-up call to the challenges was as a young zoology graduate student involved in a global population conference in Fall,1968 (Regier and Falls 1969). It alerted me to the population explosion that was occurring throughout the 20th century (3.45 billion in 1968, now 8 billion in 2022), with many implications for society. Soon afterwards, I read the literature on global issues of concern (e.g. Ehrlich 1968, Meadows *et. al*. 1972, Dubos and Ward 1972), spurred on by *Silent Spring* (Carson 1962). Then, in my first job conducting fisheries research at sea, I saw firsthand the pollution, over fishing, and habitat damage in our Atlantic coastal waters. I continued studying and the rest is personal history, a career in the nascent Environment Canada and in academia. It was clear throughout that the list of environmental stressors is endless, against a back drop of greater numbers of people and global climate change.

Circa 2023 – on top of such problems, there is the continued and growing demand for resources (minerals, oil and gas, lumber, food, chemicals). We are clearly making huge demands of the planet, some saying that we have overshot that mark. What is our future with 8 billion people all requiring a place to live, food, essentials, health care, and security? As Paul Ehrlich and others have asked – are we at the point of continuing to extract more resources from the earth each year than we are returning to it? Will food famines, mass migrations and wars eventually overwhelm us, in addition to the current major environmental concerns of climate change, loss of biodiversity, over fishing, environmental contamination, etc.? Are we at a crucial tipping point for a livable planet? These are crucial questions that should engage us as citizens and scientists, be rigorously discussed, and foster an interdisciplinary approach to solutions with all haste.

I try to be optimistic. The good news is that many core problems are recognized, they are being well studied and considerable efforts are occurring to address them. There is much effort to optimize the science-information-policy – management interface. We should be especially thankful for the continued work of the United Nations and its many agencies and advisory groups; the UN is truly our Florence Nightingale in the efforts to care for people and the environment, and to respond to ongoing crises (wars, famines, earthquakes, floods, mass migration). Great strides have been made globally to increase food production and distribution. Advances in medicine continue, at times seemingly miraculous as shown by the rapid production of novel and effective vaccines in the recent (and still ongoing) Covid pandemic. Finally, diplomacy continues on many fronts to diffuse confrontations and increase understanding and cooperation in this rapidly changing world.

That said, there is an ongoing climate crisis, recognized now by most governments and influential groups. Climate change is here, the globe is warming. This will be a primary concern for the rest of the century (see the references and the last IPCC report). As well, pandemics will likely recur as history repeats itself.

Solutions for many of the above mentioned problems have scientific, technological and social underpinnings. Reliable, salient and timely information is always needed, hence the continued role of science and the communications work of groups such as the NSIS. The NSIS should continue to be a hot bed of talks and actions on these important topics, utilizing the immense scientific resources of Nova Scotia and the Atlantic region. The problems that we face require discussion, collaboration, scientific and social understanding, and above all, timely decision making and action.

In support of this, it is crucial to have the engagement of NSIS members with those from other societies in NS and the region – working together, sharing reliable information, encouraging the engagement of young people, discussing key issues, and looking for solutions that work. That is the only way to look after our environment, ourselves and the future of the planet. Where we can, we must also engage the help, support and action of governments at all levels.

While you ponder this challenge, browse the content of this PNSIS issue. There are articles on a range of topics, from fungi to fish, developmental biology, climate change and science history, as well as remembrances to past distinguished NSIS members. For the first time, a report on the NSIS summer excursions of 2023 is included, and the book reviews remain popular with readers.

Please consider contributing to the varied NSIS program of activities. Encourage your colleagues and students to join the NSIS and attend our monthly talks. Our journal, the PNSIS, is one voice piece for science and science-based action on crucial information-based issues in Nova Scotia and throughout the Maritimes. Consider sending in a contribution to the next Issue. Perhaps offer an alternative view to this polemic, penned by a "despairing optimist" (Dubos 1970) in a year of much change and concern for our future.

*Acknowledgements* Many thanks are owed to the contributors, reviewers, and the Editorial Board for this Issue of the PNSIS. I also thank David Richardson (SMU), Jon Percy (SEAPEN and BoFEP), and Mike Butler (International Ocean Institute – Canada) for their comments on the draft of this article. It is dedicated to

the memories of Nova Scotia colleagues Meinhard Doelle, Alan Ruffman and Charles Schafer, who have recently passed away but have left long-lasting legacies in their fields of specialty – international law, geology, environmental activism, and oceanography.

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# TURN ON THE LIGHTS! FUNDAMENTAL SCIENCE LEADS TO SCIENTIFIC PROGRESS: A PERSPECTIVE FROM DEVELOPMENTAL BIOLOGY

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## ABSTRACT

Many of the ways in which we interact with the world around us have been shaped by the dual efforts of fundamental and applied sciences. Generally speaking, fundamental science generates knowledge about how things work at a fundamental level, and applied science employs this body of knowledge to create a new product or overcome an existing challenge. Developmental biology is a classic example of fundamental science that drives several avenues of applied science. For example, understanding how cells, tissues, and organs develop, and are coordinated within a functioning organism can form the basis for diagnosing medical conditions and exploring treatments. As a developmental biology lab researching bone and cartilage in birds and fish, we are acutely aware of the disparity in financial support between fundamental and applied

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science research in Canada. Funding cutting-edge applied research with immediate impacts on society is attractive and more easily justifiable to tax payers. However, funding grassroots fundamental science research is equally important but receives significantly less attention and support because the impacts are harder to predict and are longer-term. This commentary addresses this inequity in science funding and highlights the dire need to improve supports for early career scientists.

Keywords: Fundamental science, developmental biology, students, Canada, science funding

## INTRODUCTION

Both fundamental science research and applied science research involve critical thinking and developing international and national collaborations. In Canada, there are many funding initiatives to support applied science research, however, the importance of fundamental science is often overlooked yet underlies the advancement of society (Naylor *et al.* 2017). The ripple effects of fundamental science are a major driver of economic growth. Unfortunately, as noted in the Naylor report (Page 19, xix) in 2017, the Canadian government continues to fund applied science research over fundamental science. There are major federal funding sources for fundamental science (e.g., the Natural Sciences and Engineering Research Council of Canada, NSERC, Discovery Grants program) but they are limited. In contrast there are numerous funding opportunities for applied research (NSERC alliance grants, Canadian Institutes of Health – CIHR grants, MITACs grants, New Frontiers Grants, etc.). This article describes why fundamental science deserves more attention and needs more federal and institutional support. We also highlight the impact that under-funding has had on the well-being of scientists.

## THE SCIENTIFIC PROCESS

All science research, whether applied or fundamental follows the same scientific process. This is an iterative process, which involves a series of steps that start with a thorough understanding of the knowledge that has previously been gained in the specific research area. With this basis, scientists develop the study objectives, a hypothesis and the methodology and approach (Atkamis & Ergin 2008). Controlled experiments with measurable results ARE validated by appropriate statistical analyses AND are essential for scientific discovery.

Skilled people are required to design and execute a study. A well-designed project requires including people with different experiences and perspectives during the design phases (Powell 2018). The output of science in terms of published research papers is often considered the most important aspect of one's research, and this aspect is primarily judged during grant reviews. However, the people that are trained during a research study are also of great importance – they are not only essential to obtain results but they are also the future knowledge holders in terms of expertise and scientific research approaches. The more scientifically literate Canada is, the better we are able to make informed decisions about our health and environment.

Another aspect of the scientific process that is often not recognized is that even if a study does not lead to a major new understanding, the process of conducting that study is nevertheless valuable. For example, the protocols and procedures of how to conduct an experiment that are developed and optimized during a study are valuable assets to future research. While scientific studies always include a methods section, these are becoming more and more abbreviated such that studies can not be repeated based on these sections alone. It is only in the last three decades that journals, which solely publish protocols or methods, have been established. Thus, the benefits of science funding are more than just the actual scientific output (i.e., the publication or the product). These added benefits apply to both fundamental and applied scientific studies. Fig 1 highlights some of the hidden and obscured aspects of science, and the important role that trainees play in science research endeavours.

## THE IMPORTANCE OF FUNDAMENTAL SCIENCE

The scientific discoveries made within Nova Scotia are numerous. Well-known inventions include the Silver Dart, designed by Graham Bell, which was the first aircraft to make a controlled powered flight in Canada and the British Commonwealth in 1909. A lesser-known example was the invention of modern paper by Charles Fenerty in Halifax, NS in 1844. He was the first to use wood pulp for paper, which revolutionized world paper production. A more recent invention was the bionic knee brace that was developed by Spring Loaded

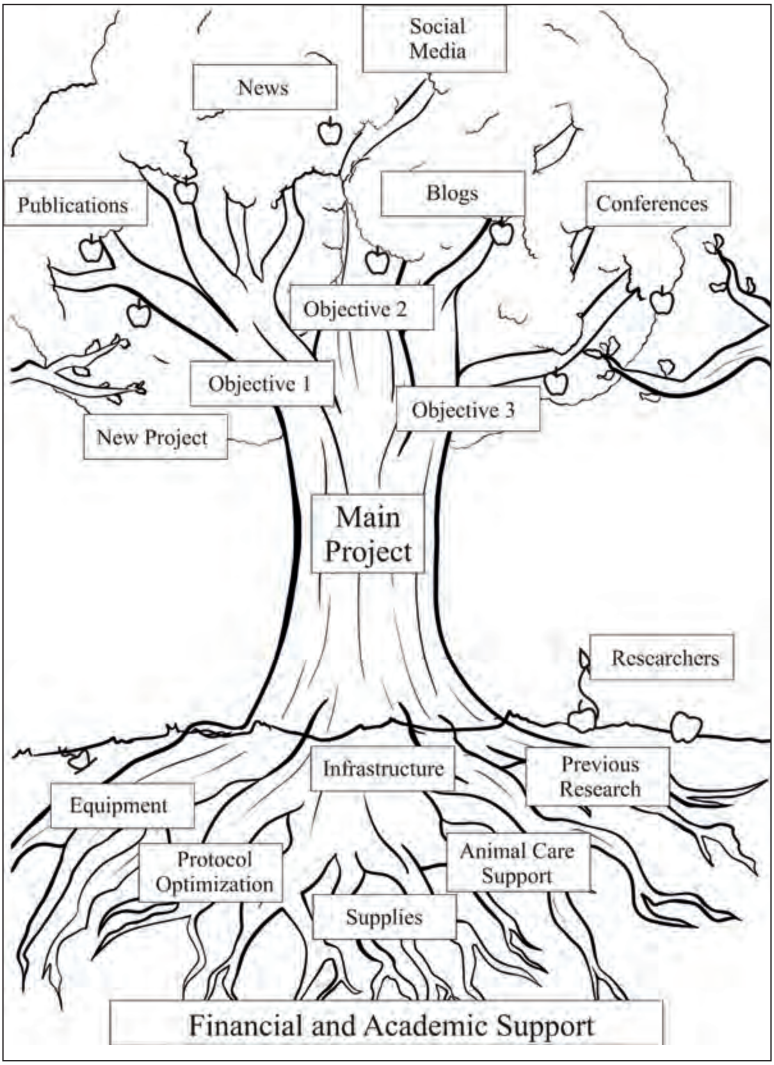


**Fig 1** **A depiction of a typical research project represented by an apple tree. The research that is visible to the public is above ground whereas the research that is hidden from the public is below ground. For example, results of scientific studies are often shared at conferences, in publications and on social media. Below ground, this research is supported by the purchase of equipment and supplies, by previous research and by establishing optimized protocols. Importantly, the researchers (i.e., trainees, students) conducting the science research (represented by apples), are often obscured, they may drop off the project and start their own research group, or they may leave science all together. Principal investigators design the project and ensure its success.**

Technology in Dartmouth, NS in 2016. These examples have been mentioned in the proceedings of the Nova Scotian Institute of Science published since 1864. These examples are of applied research leading to a product and they were made possible by existing fundamental knowledge. An understanding of developmental biology and the anatomy of how tissues interact underpins the knee brace invention, cellular chemistry underpins the paper invention and the invention of powered flight was not possible without an understanding of the physics of air flow, metallurgy and the chemistry of oil and combustion. Thus, years of fundamental science research preceded these inventions.

Throughout history, global crises lead to pivotal points for life-changing innovations and discoveries. A recent crisis is the COVID-19 pandemic, which rapidly had an impact on the lives of millions of people. The development of the COVID-19 vaccines was the result of previous scientific knowledge which enabled the rapid development of vaccines in response to this pandemic (Kashte *et al.* 2021). Researchers had to look for a solution to provide protection against this strain of COVID, and to understand it, they had to investigate where it came from, how it enters and impacts the body, and finally, how it can be managed. These questions were answered by investigating RNA viruses, testing a multitude of techniques, and developing solutions and vaccines. Under the pressure of a worldwide crisis scientists needed to produce a fast response and this was achieved with the help of governments who provided significant funding. This all contributed to the rapid development of COVID-19 vaccines with many scientists around the world collaborating. Without fundamental knowledge, however, it would have taken much longer to design the strategies required to address the COVID-19 pandemic. Scientific discoveries are the result of a solid fundamental research base that is continually reinforced and expanded by scientists (Fig 2).

## WHY DEVELOPMENTAL BIOLOGY IS IMPORTANT

Developmental biology is one of the oldest fields in biology and dates back 500 years when the focus was centred on anatomy and the comparative morphology of organisms (Schoenwolf 2002). Today, it is one of the core fields of vertebrate biology. Filled with

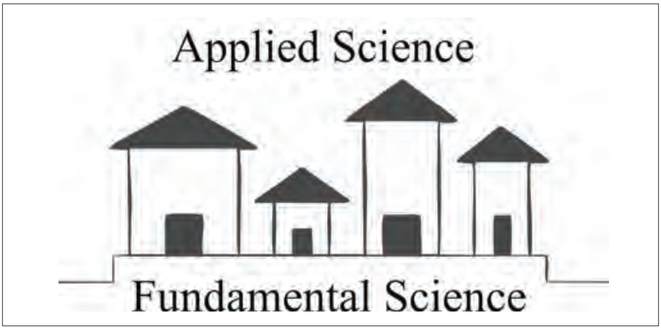


**Fig 2 Metaphorical representation showing that fundamental science is the foundation on which all applied research projects are built, regardless of the field.**

wonder for the diversity of animals, scientists turned to understand how this diversity arose by studying the embryos of animals. The field now known as developmental biology studies the development and growth of both plants and animals.

With the advancement of genetic and molecular biology techniques in the last century, these descriptive studies have been complemented by experimental embryology studies, which assess how organisms develop at the cellular and tissue level. Developmental biology research is incredibly useful in that it spans the gap between the cellular and molecular levels, and the systems and organismal levels. Developmental biology generates knowledge for other fields of research, such as anatomy, stem cell research, genetics, neurobiology, cancer biology, and evolutionary biology (Fig 3, Gilbert 2017). Understanding how organisms normally develop helps to provide information on the progression of diseases that may arise during development (i.e., congenital disorders) or those that arise later in life (e.g., osteoporosis). This understanding helps to explain, for example, why some animals are able to heal wounds and regenerate certain body parts, and also provides insights into the causes of birth defects in human populations.

More recently, developmental biologists have turned to the history of organisms to answer some of their questions in a "new" field called evolutionary developmental biology (Müller 2007). This field studies developmental processes over evolutionary time. For example, why are some birds flightless and why do snakes have no legs? Biology helps us to understand more about the world around us. It is

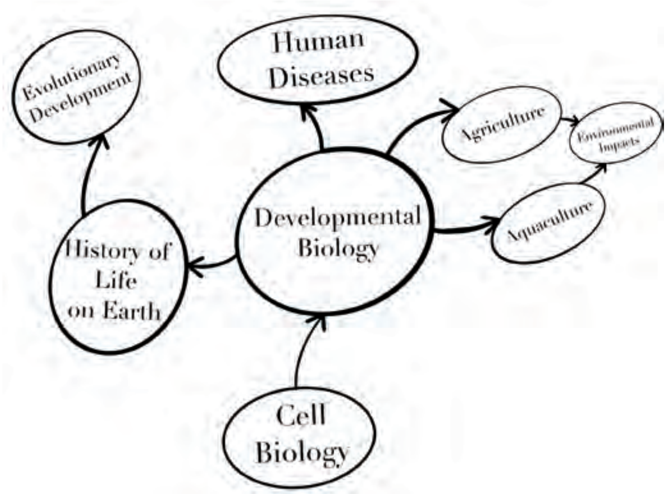


**Fig 3** **A flow chart detailing the interconnected nature of some common fields of biological science, and how these fields are connected to developmental biology.**

the inter-connectedness of many fields of biological research that has led to progress in fundamental research, and ultimately to progress in our society (Naylor *et al.* 2017).

## SKELETAL BIOLOGY RESEARCH

Our research group conducts fundamental science research to understand the development and growth of bones and cartilages of vertebrates. Because studying the cells of human embryos is difficult, scientists often turn to animal models. What we learn about bone and cartilage development from our work is important for applied research (e.g., to understand congenital birth defects, environmental effects on the skeleton, space biology, etc.)

We utilise two model organisms to answer different research questions. One of the traditional developmental biology animal models is the chicken (*Gallus gallus*). Eggs are easily obtainable and embryos are large (e.g., Stern 2005, Burt 2007). These embryos are also easy to access, manipulate, and observe. Chickens are one of many bird species that have ocular skeletons. These are bones and cartilages within the eyeballs that support the retina. Ocular skeletons have a long evolutionary history among vertebrates. Our research over the last decade and a half has explored how bones and cartilages develop in birds as well as in bony fish. The other model organism we use is the common zebrafish (*Danio rerio*). This fish offers advantages, such as ease of reproduction and rapid development (Mariotti *et al.* 2015). We use this organism to study environmental impacts on the growth of the skeleton since the entire lifespan or life cycle of zebrafish can be studied in the laboratory.

A key aspect of development of the skeleton is ossification. Ossification is the series of processes that occur during the formation of bones and can be broadly split into one of two categories: intramembranous ossification and endochondral ossification (Hall 2015). Intramembranous ossification results in the formation of bone directly from the surrounding tissue without the need for a pre-existing template (e.g., development of the skull roof). Cells intercommunicate to form an aggregation or cluster of cells, which then directly differentiate into bone cells (i.e., osteoblasts and osteocytes). In contrast, endochondral ossification first requires the formation of a cartilaginous template, which is later replaced by bone (e.g., long bones in arms, wings and fins). As part of the replacement process, the cartilage must be broken down and resorbed to make room for bone tissue to form. There are still many large gaps in our understanding of bone formation and resorption – what mechanisms are used to direct cell aggregation and differentiation into bone cells, and what changes need to occur in cartilage tissue prior to resorption? Whereas these fundamental questions still remain, their answers have massive impacts on our understanding of the overall development, growth, and maintenance of the skeleton. This knowledge is critically important if we want to understand and treat human skeletal disorders. In our research group, we have uncovered some of the key signaling pathways in the earliest stages of bone development and how these genes interact (e.g., Duench and Franz-Odendaal 2012, Jourdeuil and Franz-Odendaal 2016, Giffin and Franz-Odendaal 2020).

One of the problems facing human civilization is how to survive extreme environments. We highlight our research as an example of the research in this field taking place in Nova Scotia. We focus our research on the effects of vibrations and microgravity. After a space trip, astronauts face several health issues, but one of the main problems is a substantial loss of bone mineral density recorded at an alarming rate, about 1.5% per month in long duration spaceflights

(Iwamoto *et al.* 2005, Sibonga *et al.* 2015). The loss of bone density imposes a high health risk in astronauts as it reduces their fitness, and increases the risk of fractures and body support (Sibonga *et al.* 2015). We use zebrafish and/or their scales in a random positioning machine or on a vibration platform to understand the effects of these environmental stressors on the skeleton. Zebrafish have scales composed of a thin layer of bone and we can use these scales as an *in vivo* way to study the responses of adult bone tissues. Larval fish can be placed into the random positioning machine or on the vibration platforms to determine the effects this has on their skeletal growth. We have the tools and methods to study these effects, through fluorescence microscopes, as well as to study changes in bone morphology, disruption of tissues and organs, and changes in gene expression in the tissue (e.g., Duench and Franz-Odendaal 2012, Giffin and Franz-Odendaal 2020). These results will generate a basis for future research in the use of developing organisms on board the International Space Station. Understanding developmental biology should enable scientists and engineers to design methods to circumvent environmental stressors such as zero-gravity and vibrations.

## INEQUITIES OF SCIENCE FUNDING IN CANADA

Many important discoveries in science have been incredibly serendipitous: take for example the discovery of penicillin by Sir Alexander Flemming (Hare 1970, Ligon 2004). Many other important discoveries in science have been the result of chance encounters – showing that science is non-linear, and it is often unknown where a given project will lead. While many perceive scientific research as an objective study of the universe that is free from outside influence, it is critical that we recognize the effects that biased funding decisions have on scientific progress. A poignant example of this is the impact of the sugar industry on health research in the 1970s (Kearns *et al.* 2015). Here, scientists were influenced by funding sources from within the sugar industry to favour the publication of studies that suggested that a low-fat, high-sugar diet was healthier to consume (e.g., Larsen and Dougall 2017). This led to a massive increase in sugar sales, at the overall expense of societal health. In contrast, cultures that support and encourage scientific research often are responsible for massive advances in their fields; for a period of 500 years, the Arabic-Islamic world led a golden age of science due to the religious emphasis on research and scholarship (Faruqi 2006). The impacts of this golden age are still felt today and it is clear that society can have massive impacts on science outcomes.

One would think that an equal opportunity would be given to funding scientific research for each and every scientifically sound project. While this may be how it appears to the public, the bias in scientific funding is apparent to those within the science sector. The outcome of grant applications often reflects how a project is marketed and its short-term impact rather than the value that the research may bring to society decades in the future. In Canada, the federal government funds research through three main funding bodies: The Natural Science and Engineering Research Council of Canada (NSERC), The Canadian Institute of Health Research (CIHR), and the Social Sciences and Humanities Research Council (SSHRC). These three agencies (known collectively as the Tri-Council) are responsible for funding much of the research that occurs in public institutions. When looking at the size of the grants that fund science from each agency (NSERC Discovery Grants, CIHR Project Grants, and SSHRC Insight Grants), it is clear where the priorities of the Federal Government lie. The average CIHR Project Grant is valued at $174,320, the average SSHRC Insight Grant is valued at $158,074, and the average NSERC Discovery Grant is valued at $36,516 (CIHR 2021, NSERC 2021, SSHRC 2021). Only the latter grant type funds fundamental science research and a researcher can only hold one of these grants at any one time. This is in stark contrast to applied science research, in which a researcher can hold any number of these grants concurrently, and often with higher funding envelopes. Clearly, with this structure, the progress in fundamental science research in Canada will be at a much slower pace than that in applied science projects.

One particularly important group that is disproportionally impacted by the current funding system is graduate students (Graddy-Reed *et al.* 2021). These students typically begin their graduate studies shortly after finishing their undergraduate degree; meaning that these students typically haven't had access to well-paying employment to save a meaningful amount of money to help cover expenses (e.g., rent, utilities and essentials, medical expenses, etc.) during their studies. Thankfully, many programs guarantee stipends for each student, with the idea that graduate students should be able to commit fully to their research without the need to worry about their financial situation. Often the research students involved also work as Teaching Assistants, which provides financial support, but reduces the time available to do the required research. Despite the availability of stipends, institutions still fail to provide adequate financial security for their graduate students.

The graduate school experience is one that can often be characterized by scathing self-criticism, anxiety, and overwork. A quick internet search turns up countless discussions concerning these issues and how graduate students can suffer damage to self-image and physical health (Okoro *et al.* 2022). Graduate school is inherently stressful because of the nature of a thesis and is made significantly more stressful by financial worries. Much of the mentoring and bench-level work conducted in academic labs is done by graduate students, and therefore the stress experienced by graduate students has cascading effects across the academic system. Without adequate support for graduate students, it is very difficult for research groups to produce high quality, grant-winning research. Principal investigators are also pressured to train more graduate students in order to successfully secure funding, which is then not adequate to support these students. Clearly, more investments must be made to improve the well-being of graduate students, in addition to a dire need to increase the funding that supports these students. This is particularly true for those students conducting fundamental science research and who are dependant on NSERC for funding.

## CONCLUSIONS

Our intent with this article is to shed light on overlooked aspects of conducting scientific research and the critical need for significant increases in the recognition of the importance of fundamental science that fuels the success of applied science projects. In Canada, there is a dire need to significantly increase funding to support trainees (students and postdoctoral fellows) within research groups. The huge discrepancy in funding dollars for fundamental science compared to applied research must be addressed, as previously highlighted in the Naylor report (Naylor *et al.* 2017). We need to avoid elitist funding where a few researchers get millions of dollars while others have to make do with very modest and often inadequate amounts. Fundamental science is the driver of applied research and should be recognised as such by funding bodies and society in general. It is time to reassess the funding of science in Canada to be more equitable across disciplines and research areas.

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# CLIMATE CHANGE AND THE COASTS OF MARITIME CANADA: EXPECT THE PREVIOUSLY UNEXPECTED

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Hurricane Fiona battered the Canadian Maritime provinces (New Brunswick – NB, Nova Scotia – NS, and Prince Edward Island – PEI) on 24 September 2022. It was a record-breaking storm in several regards. At St. Peters, PEI (Climate ID 8300562), the barometric pressure dropped to 95.23 kPa and wind gusts of up to 140 km/hr from the north were recorded. The storm surge was at least 2 m (Mulligan *et al.* 2023) and news media reported on widespread damage to coastal infrastructure and significant coastal erosion. In the following weeks, I visited several sites in PEI National Park and NB (the Shediac and Bouctouche areas) to survey the damage. The impacts of Hurricane Fiona were readily apparent at all north-facing coastal sites visited (Fig 1). So, was Fiona 'unprecedented'? Do the impacts of Fiona represent the future for the coasts of Maritime Canada? As it turns out, this is a difficult question to answer, primarily because by the time we have sufficient data from major storms to draw statistically significant conclusions, it will be too late to adopt some solutions/responses. We must therefore rely on computer models, data from other regions, and on our own observations to judge what we might expect in the coming decades at our Maritime coasts.

Just as Fiona battered PEI in 2022, Hurricane #5 battered PEI in 1923 (MacEachern 2022, Mathew *et al.* 2010). Damage from Hurricane #5 was widely reported at the time in the newspapers of the day. Wharves were damaged, bridges and rail lines washed away, barns flattened, and so on. To the best of my knowledge, the storm surge associated with Hurricane #5 produced catastrophic overwash along the whole length of what is now the Greenwich Dunes section of PEI National Park, which is about 10 km west of St. Peters (Mathew *et al.* 2010). The 1936 aerial photos show complete destruction of all

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**Fig 1** **The Pointe-du-Chêne Wharf, NB, on 24 September 2022, a few hours after the passage of Fiona. Note the Sandbar Restaurant that was pushed off its foundation (which also happened during Hurricane Dorian in 2019) and the wharf's fuel tanks that were pushed into the road. Photo credit: Andrew Ollerhead.**

foredunes. It took nearly 40 years for a continuous foredune system to become re-established at Greenwich, and a further 30 years before the inland dunes stabilized. Details of the recovery process can be found in Mathew *et al.* (2010).

Given that Fiona was at least as powerful as Hurricane #5, why was there not more coastal erosion and damage? Why did Hurricanes Dorian (7-8 September 2019) or Juan (29 September 2003) not cause as much coastal erosion and damage? Over the course of our research (e.g., Ollerhead *et al.* 2013) it has become clear that storms of similar magnitude do not result in a similar amount of geomorphic work being done nor, apparently, the same amount of damage to infrastructure. Some of the reasons for this can be explained by advances in technology. Bridges built in recent decades are constructed with concrete and/or steel and placed well above the highest expected water level. Most bridges built 100 years ago in PEI were constructed of wood and were likely not well above the highest expected water level (A. MacEachern, personal communication). Buildings are now engineered to higher standards and constructed with certified materials.

Thus, less infrastructure damage today cannot be viewed as evidence of a less intense storm. This is not, however, the case for our natural coasts, which unless armoured, have much the same geomorphology today as 100+ years ago.

Determining whether our Maritime coastal geomorphology is now being impacted to a greater degree by climate change is difficult and may well be impossible. Controlling parameters that operate on a decadal-to-century scale, like bedrock geology and rate of relative sea level rise (RSL – the combination of rising global sea level and any rise or fall of land level), can be predicted and/or measured with relatively high confidence. Likewise, controlling parameters that operate on an annual-to-decadal scale, like sediment budget or vegetation cover, can be predicted and/or measured with relatively high confidence. What is difficult or impossible to predict, more than a few days or weeks in advance of a storm, are those controlling variables that operate on a weekly to monthly scale, such as presence/absence of embryo dunes in front of a foredune system, amount of sea ice that can offer storm protection, and time in the tidal cycle. As an example, a storm of a given magnitude will have different impacts on the coast if it passes coincident with neap low tide after a period of relative 'calm' than if it passes coincident with spring high tide during a particularly active storm season. Put another way, antecedent environmental conditions and storm timing matter a great deal in terms of how a coastal system responds to a given storm.

From a management perspective, the importance of the storm frequency and magnitude question lies in understanding both the impacts of human actions on coastal systems and on predicting how those systems are likely to respond to natural events, particularly as our climate changes. For example, Naylor *et al.* (2017) present evidence demonstrating how antecedent geomorphic and climate parameters can "alter the risk and magnitude of landscape change caused by extreme events" (p. 166). They argue that "adopting geomorphologically-grounded adaptation strategies will enable society to develop more resilient, less vulnerable socio-geomorphological systems fit for an age of climate extremes" (p. 166).

A significant challenge to influencing public policy is that by the time we are confident that climate change is affecting our coastal systems, it will be too late to take some actions. As an example, sea ice coverage data for the Gulf of St. Lawrence over the past 50 years are highly variable (Fig 2). Maximum ice coverage has decreased by about 0.20% per year over the period of record and the trend is statistically significant. However, the highest value since 1968/69 was in 2002/03 (58%) and the lowest value was in 2009/10 (12%) – both within the past 20 years. Thus, the amount of sea ice, which can protect the coast from erosion during winter storms (Manson *et al.* 2016), is highly variable from year to year. Recent work by Keefe and Wang (2023) illustrates the same point. To develop a comprehensive understanding of winter ice formation around PEI, historic ice coverage data from 1981 to 2023 for 50 locations around the Island were analyzed. They also found high variability from year to year but demonstrated that at every site, there was decreasing ice coverage over the study period, with a loss rate of approximately 1.1 weeks of ice coverage per decade (Keefe and Wang 2023). These results agree with those of Senneville *et al.* (2014) who found that average annual sea-ice cover on the east coast of Canada has decreased by 0.27% per year since the Canadian Ice Service began collecting data in 1968/69. Senneville *et al.* (2014) also found that for the period 1998–2013, the average decrease was 1.53% per year and they projected that sea ice will be almost completely absent in most of the Gulf of St. Lawrence

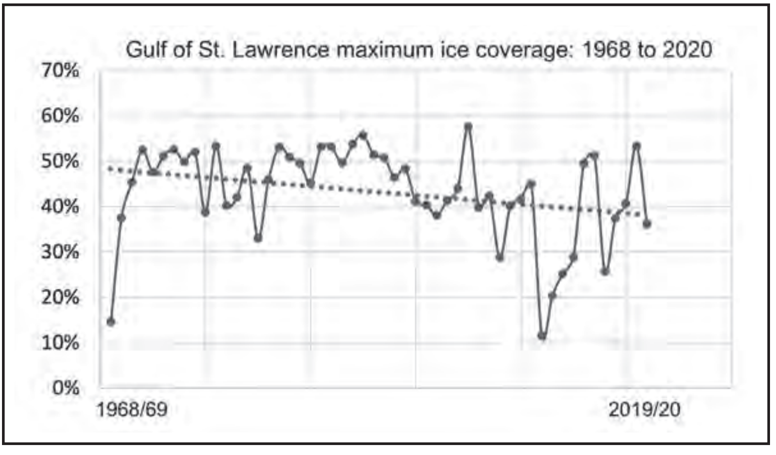


**Fig 2 Gulf of St. Lawrence maximum ice coverage plot (% of total area) for 52 seasons (1968 to 2020). The linear regression line is significant *($p < 0.05$)* and the slope is approximately -0.20% per year. Data are from: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/climatology/gulf-st-lawrence-graph-1968-2016.html**

by 2100. The challenge is that by the time a clear trend for annual winter sea ice coverage in the Gulf emerges in the public and/or decision makers' minds, it will be too late!

Likewise, having looked at storm data for PEI for the past 100 years, it would be challenging to prove that major storms are becoming more frequent and/or severe in the Maritimes. In my time living in New Brunswick (since 1994), Pointe-du-Chêne has been flooded by significant storm surges in 2000, 2010, 2019 and 2022. Is this a trend of increasing major storms? I don't know. Thus, I turn to the Intergovernmental Panel on Climate Change (IPCC) for the best guidance available – specifically the IPCC's 6th assessment report or AR6 (IPCC 2023) which summarises the latest state of knowledge on climate change, its widespread impacts and risks, and climate change mitigation and adaptation options. A key question is whether our observations over the past 2-3 decades appear to fit with what has been predicted by the IPCC (2023)?

The longer synthesis report of AR6 was released in March 2023 (IPCC 2023). It states upfront that "The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years." (p. 11). It presents data showing that "The average rate of sea level rise was 1.3 [0.6 to 2.1] mm $yr^{-1}$ between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm $yr^{-1}$ between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm $yr^{-1}$ between 2006 and 2018 (high confidence)." (p. 11). It asserts that "Human-caused climate change is already affecting many weather and climate extremes in every region across the globe" and that "It is likely that the global proportion of major (Category 3-5) tropical cyclone occurrence has increased over the last four decades." (p. 12). A striking aspect of AR6 is that the predictions are, in many cases, more dire than those of AR5 from 2014. As time passes, the risks and consequences to human infrastructure and our ecosystems are increasing.

Sadly, AR6 makes it clear that there are gaps between stated global ambitions to tackle climate change and the sum of declared national ambitions to do so. Modelled pathways "consistent with the continuation of policies implemented by the end of 2020 lead to global warming of 3.2 [2.2 to 3.5] °C (5-95% range) by 2100 (medium confidence)." (p. 33). Regardless of what we do, "Global warming will continue to increase in the near term in nearly all considered scenarios and modelled pathways." (p. 33). Specific to coasts, it points out that "Sea level rise poses a distinctive and severe adaptation challenge as it implies both dealing with slow onset changes and increases in the frequency and magnitude of extreme sea level events (high confidence)." (p. 44).

Put simply, if one accepts the findings of the IPCC's AR6, one must accept that our Maritime coasts and coastal communities will face accelerating relative sea level rise, the loss of protective sea ice where applicable, and an increase in the frequency and magnitude of major storms over the balance of this century and beyond. Recent observations in Maritime Canada appear to fit the IPCC (2023) predictions. We cannot wait until we have enough data of our own to test these conclusions. Comparing Fiona and Hurricane #5 is insufficient to draw conclusions. Thus, our communities and governments need to plan now for the expected realities. Simply adding shoreline armouring or raising buildings by 50 cm will not be sufficient, despite the fact that in some locations, hardening the shoreline and raising infrastructure may be necessary as the only 'feasible' short-term choice. In many other locations, however, we should be open to alternatives such as relocating infrastructure and leaving accommodation space into which mobile coastal features can migrate (e.g., salt marshes, barrier islands, sandy beach and dune systems, and so on). Rebuilding or re-establishing salt marshes and sand dune systems helps to mitigate impacts.

As Lane (2020) argued, action on climate change is needed now. Lane (2020) suggests several ways to do this, including a call for "increased investments … to be directed to communities so that they can take more responsibility and be more prepared to live with climate change impacts" (p. 237). Lane (2020) also suggests that encouraging action requires "science-based information and education whereby climate action is clearly defined along with the consequences of actions (or inaction)" (p. 237). I am skeptical of this latter argument for our coasts, however, as I don't view lack of "information and education" as part of the problem. Lemmen *et al.* (2016) edited "Canada's Marine Coasts in a Changing Climate" which has detailed information on climate change, its consequences, and suggested actions for all of Canada's coasts. It is a worthwhile read for anyone interested in the subject. Put plainly – there is no shortage of information available.

In the case of our Maritime coastal communities, informed planning is now needed to prepare for the future that is coming. Even though we cannot confidently attribute any given extreme weather event specifically to climate change, we will likely have to leverage the damage done by such events to amplify calls for action. It takes time to build relationships within communities and with local governments, and to assist them in assessing options. The time to plan is not during or immediately after a major storm like Fiona. The tendency then is to put things back the way they were. Communities should think carefully about how they build or rebuild in hazardous locations. At Pointe-du-Chêne Wharf (Fig 1) the fuel tanks displaced by Fiona have been returned to their pre-Fiona locations, apparently with better anchoring, but at the same locations nevertheless.

As noted in the IPCC's (2023) AR6, our responses to climate change will be "more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and underpinned by inclusive community engagement processes (high confidence)." (p. 44). Communities should be encouraged to consider how nature-based solutions as a response provide co-benefits (Bridges *et al.* 2021). As an example, if a salt marsh is restored or created in front of a new dyke, not only are the ecosystem benefits of a salt marsh gained, but organic carbon compounds are sequestered too, and natural protection in front of that dyke develops which has the potential to grow vertically and keep up with relative sea level rise without the need for expensive maintenance (Sutton-Grier *et al.* 2015). Likewise, a healthy coastal dune system provides natural protection from coastal flooding during major storms.

Climate change and how to respond and adapt to it is arguably one of the greatest challenges to face humanity – ever. The impacts will, of course, vary with location. In some places relative sea level (RSL) is falling (*e.g.,* parts of Newfoundland and Labrador) so the strategies employed by coastal communities in those locations to prepare for climate change will not necessarily be the same as in most of the Maritimes, where RSL is rising. Regardless of local differences, if we continue to develop and build along our coasts in the same manner as in previous decades, we should expect ever increasing damage to our infrastructure and financial losses over the coming decades. Put simply, we must now expect the previously unexpected, and start to prepare and respond creatively and effectively. Our coasts and coastal communities deserve nothing less.

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# ALL IN DUE TIME: (SIR) SANDFORD FLEMING ARRIVES IN HALIFAX

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## ABSTRACT

Through the greater part of the nineteenth century and early twentieth century the life and work of (Sir) Sandford Fleming's encompassed many different worlds, and often on a global scale. He developed the model for Universal Standard Time. Considered a "larger-than-life" figure of extraordinary passion and vision, he became a highly-skilled railroad engineer. He also had a passion for telegraph systems. In the parlance of the 19th century, he was known as an "Empire builder," and was knighted in 1897 as a distinguished inventor and scientist. In the twentieth century, Fleming became known as a "promoter" and "networker" par excellence.

Fleming conversed and worked with everyone from indigenous guides and men constructing railways through the hinterland, to politicians and bureaucrats funding railways, as well as boardroom shareholders and investors, university academics, and on occasion, royalty in an opera box in Paris!

Sir Andrew MacPhail once said of Fleming that he may not have been the greatest engineer who ever lived; he was merely "the greatest man who ever concerned himself with engineering."[1] For Fleming, engineering was the link between science and society and integral to his view of knowledge and the use of technology.[2] He saw railways and telegraph cables as part of an overall system of global transportation and communications leading to his model of Universal Standard Time.

This commentary focuses on a period in Fleming's life and times when he had arrived in Halifax in late 1863, a time when, later in 1867, the Dominion of Canada was formed and created an urgent need to link the provinces via a railway service, for both communications and defense. In Halifax, Fleming established important friendships and associations that led to him spending many summers in the province with his family and being involved in several large projects.

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1 Time and Sandford Fleming. *The Royal Bank of Canada Monthly Letter* 59 (8), August 1978.

2 Blaise, Clark (2000). *Time Lord.* Alfred A. Knopf Canada, Toronto. p. 49.

## ARRIVAL IN CANADA AND EARLY ACTIVITIES IN ONTARIO

On 19 January 1863, members of the Nova Scotian Institute of Natural Science (now known as the Nova Scotian Institute of Science) gathered for the first time in Halifax to share recent research activities in the province.[3] Two years later, (Sir) Sandford Fleming (1827-1915) joined the Institute. Prior to arriving in Halifax, in 1863, Fleming had been residing in Toronto with his young family where he had been working on the construction of the Ontario, Simcoe and Huron Railroad line (later renamed the Northern Railway Company) – starting as an assistant engineer in 1852, and then later appointed Chief Engineer, until the end of 1862.

Early in 1863, Fleming accepted a commission from the pioneering Scotch settlers in the isolated Red River Colony (near today's Winnipeg) to seek the interest of the British government in a plan to construct a pioneer road, a telegraph line, and then a railway link from the eastern provinces to the settlement and on to British Columbia – referred to as the Red River Memorial. He left for London in May, but his consultative efforts were not a success.[4]

Fleming's trip to Great Britain was one of 44 transatlantic voyages that he made in his lifetime after emigrating to Canada from Kirkcaldy, Scotland in 1845 at the age of 18. After settling briefly in Peterborough, Ontario, he later obtained his land surveyor's license and moved to Toronto (pop. 20,000) where he became one of Canada's first lithographers.

[3] The Institute's first president was the mayor of Halifax at the time, lawyer and politician, Philip C. Hill (1821-1894). He would later also become the 3rd Premier of Nova Scotia (1875-1878).The proceedings of the Nova Scotian Institute of Natural Science (published from 1863 to 2013) are hosted online by Dalhousie University Libraries. https://dalspace.library.dal.ca/handle/10222/11192. Now known as the Nova Scotian Institute of Science, its proceedings can also be found online. https://ojs.library.dal.ca/nsis

A review of the membership list from 1863-1874 encompasses men in politics and law, educators in science and engineering, academics, artists and architects, as well as church ministry, the military and the business community.

[4] On 23 March 1863, Sandford Fleming had presented the wishes of the Red River Settlement to the Right Hon. Charles Stanley, Viscount Monck, Governor General of British North America, as published in the *Memorial of the People of Red River to the British and Canadian Governments, with remarks of the Colonization of Central British North America, and the Establishment of A Great Territorial Road from Canada to British Columbia, 1863*. He was advised to proceed to Britain with his concerns and proposal. The first transcontinental railway across Canada, the Canadian Pacific Railway (CPR), did not commence until 1881.


**Fig 1 The Three Pence Beaver Canada postage stamp designed by Sandford Fleming and issued on 23 April 1851.**

With new-found colleagues, he helped establish the Canadian Institute in June 1849 – with sixty-four members attending their first annual general meeting. Later it was named the Royal Canadian Institute for Science (RCIS). Fleming lived to celebrate its 50th anniversary. The Institute was formed for "the encouragement and general advancement of the Physical Sciences, the Arts and the Manufacturers in this part of our dominions."[5] The society's journal (started in 1852) was the first in Canada to be widely distributed internationally.[6] During this time, Fleming was also commissioned by James Morris, the Province of Canada's first postmaster general, to design a postage stamp – which became the three pence Beaver stamp – issued on 23 April 1851 (Fig 1).

A year later, he began work as an assistant railroad engineer with the Ontario, Simcoe and Huron Railroad. Eleven years earlier, at the age of 14, Fleming had apprenticed for four years with the Scottish railway engineer John Sang, learning the skills of land surveying and railway engineering in Scotland.

Within three years of starting his work with the Simcoe and Huron railroad, Fleming married Peterborough resident, Ann Jane "Jean" Hall. Her mother, Ann Jane Albro, was born in Dartmouth, Nova Scotia in 1811, while her father was the Scottish born, Ontario MP James Hall. Fleming and Jean had nine children, six of whom lived into adulthood.[7]

5 Burpee, Lawrence J. (1915). *Sandford Fleming Empire Builder. Oxford University Press,Toronto.* p. 37.

6 Ibid, pp. 38-39. The journal was first known as *The Canadian Journal* but later, from 1852-1855, its title was changed to *The Canadian Journal, A Repertory of Industry, Science, and Art,* and then in 1856 to *The Canadian Journal of Science, Literature, and History.*

7 Sandford Fleming (age 28) married Ann Jane (Jean) Hall (1831-1888) on 3 January 1855, in Peterborough, Ontario, Sandford and Jean would have nine children of which

**Fig 2 Sandford Fleming as a young man, 1855-1860. Unknown photographer. Library and Archives Canada.**

## MOVING TO HALIFAX

When Fleming (Fig 2) returned from Britain in the summer of 1863, the Province of Canada (Ontario/Quebec), along with Nova Scotia and New Brunswick, were preparing to fund a preliminary survey for the possibility of an Intercolonial Railway (ICR) line from Quebec through New Brunswick to Nova Scotia.

The American Civil War had been raging since 1861, which brought "considerations of national security and nation-building to the fore." A rail line was now being sought for an all-Canadian route from Nova Scotia through New Brunswick that would bypass the state of Maine.[8] In the words of historian Donald Creighton, there was "a brooding apprehension of trouble." At the time, many Maritimers and Canadians had a growing anxiety as to what might be the outcome of the civil war and its implications for the British provinces.[9] There was also a growing sense of urgency to unite the British colonies into a federation for defence and communication purposes.

six would survive into adulthood – five sons, Frank "Franky" Andrew (8 Nov. 1855-22 July 1913), Sandford Hall 'Bob' (20 Nov. 1858-15 July 1945), Paul Sandford (29 Dec. 1865- 28 Feb.1866), Walter 'Arthur' L. (6 Oct. 1869-22 Dec. 1941), Hugh Percy (10 Jan. 1871-1942), and four daughters – Mary Ethel 'Minnie' (3 Sept. 1859-1945), Lily Francis (6 June 1861-1953), Jeanie (8 July 1863-1873), and Alice 'Maude' (19 Sept. 1867-16 July 1868).

8 Creet, Mario (1993). "Synopsis Sandford Fleming's Canada." Unpublished manuscript. Queen's University Archives, Kingston. p. 3.

9 Creighton, Donald (2012). *The Road to Confederation: The Emergence of Canada, 1863-1867* (Reissue). Oxford University Press, Toronto. p. 91.

Earlier in 1862, Fleming had become aware of the British Government's interest and willingness to co-operate with the provinces to construct a rail transportation link between Quebec and Halifax. He subsequently submitted a proposal to government officials in August of that year that outlined his ideas for the expansion of roadways, telegraph lines and railways from the Atlantic to the Pacific, entitled *Suggestions on the Inter-Colonial Railway, and the construction of a highway and telegraph line between the Atlantic and Pacific oceans, within British territory, respectfully submitted to the government of Canada, 5 August 1862*.[10]

In writing the proposal, Fleming had gleaned intelligence from the findings and reports of the earlier western prairie expeditions by Captain John Palliser (1857-1858-1859), Henry Youle Hind (1857-1858)[11] and Simon James Dawson (1857-1858-1859). Using such data, Fleming calculated that a transcontinental railway could be accomplished at a projected cost of "not less than $100,000,000." to build 2000 miles of track from Ontario to the Pacific coast and it would take about 25 years.[12] Ironically, by the time Donald Smith laid the "last spike" for the Canadian Pacific Railway (CPR) in November 1885 at Craigellachie, British Columbia, Fleming's earlier projected costs and time-line had turned out to be remarkably accurate. Fleming's vision and proposal of August 1862 was considered timely in addressing the sense of political urgency that was emerging.

By 9 September 1863, Fleming recorded in his diary that, "Messrs Tilley [Premier of New Brunswick] and Tupper [Provincial Secretary and later Premier of Nova Scotia] informed me that they had decided, subject to approval of their governments, to appoint me to act on behalf of Nova Scotia and New Brunswick … to proceed at once with a preliminary survey."[13]

With confirmation received from New Brunswick and Nova Scotia, by mid-December 1863, Fleming was in Halifax to begin preliminary

[10] Copies of many of Sandford Fleming's papers (and books) can be accessed at The Online Books Page. Enter Sandford Fleming and follow the links by title. https://bit.ly/42hMsUc (Accessed February 10, 2022).

[11] Sandford Fleming's younger brother, John Arnot (1835-1876), had also traveled as a surveyor with Henry Youle Hind (1823-1908) on his two prairie expeditions. Hind would later moved to Windsor, Nova Scotia in 1866. He became a member of the Nova Scotian Institute of Natural Science in 1869.

[12] Ibid.

[13] Elliott, Andrew (2017). *Highlights from Sir Sandford Fleming's Diaries*. Library and Archives Canada Blog. https://bit.ly/40WquF8 (Accessed June 1, 2022).

survey work for the ICR line. As early as 1849, Royal Engineer, Major Robinson (with Edmund Henderson and Major Pipon) had conducted a preliminary survey for a possible rail line route (known as the 'Chaleur Bay Route'). Fleming would review their intelligence, as well as other possible routes.

By 14/15 December, Fleming left from Halifax to Truro by rail, and then by a carriage trail up and through the Cobequid hills, to Folly Lake, down through the Wentworth Valley, and on to Amherst and the New Brunswick border. For the next fifteen days, he continued by either horse-and-wagon or sleigh, on through the wintered bush and snow-filled forested trails heading north and west through New Brunswick to Rimouski, Quebec. He had planned to make his way back to Ontario for Christmas – to Craigleith in the Blue Mountains region of Ontario, on the southern shores of Georgian Bay, near Collingwood, where his parents lived and where his wife and the children were planning to be. However, due to poor weather, he spent Christmas en-route. When he arrived on New Year's Day, he was joyfully greeted by his expectant wife Jean and their growing family of two sons (Frankie and Bob) and two daughters (Minnie and Lily), and his parents, Andrew and Elizabeth. He wrote in his diary that he had taken the, "Morning train to Collingwood, Stage to Craigleith – Father and Mother had all their children around them … they thought I was in New Brunswick and were astonished and glad to see me … very cold and stormy."[14]

After a few weeks of rest and family time, by early March 1864, Fleming met in Montreal with the survey group leaders he had hired for the preliminary survey work for the ICR line, assigning them various work tasks and the routes to survey. He then made plans for them to hire survey crews – this time beginning at Riviére du Loup, Quebec, the terminus of the Grand Trunk Railway, where supplies and equipment for the crews would be assigned. It ultimately took eleven months and four days to complete all their reconnaissance work, covering over 600 miles of wilderness between Riviére du Loup and Truro.

After dispatching the crews, Fleming snowshoed ninety miles overland through the wintered forests to Restigouche, and then made his way down to Fredericton to report on the progress to government officials. By late April (1864), he returned to Quebec to report

[14] Ibid.

on the progress of the survey efforts to government officials for the Province of Canada. He then left for Halifax – first by rail to Boston and then by steamer, to begin work on another project – as chief engineer with the Nova Scotia Railway (NSR) on a 51-mile extension from Truro-to-Pictou Landing, known as the 'Pictou Branch' line. The line had been authorized earlier in March by Nova Scotia's Conservative government.

The vision for the Pictou Branch rail line was to enable boat passengers arriving at Pictou to proceed by rail to Truro and then on to Halifax. It was hoped that there would eventually be a connection to New Brunswick and the west. Pictou was no stranger to railways, for in September 1839 the first railway in Nova Scotia was opened there. It was a short line from Albion Mines (Stellarton) to New Glasgow for the purposes of transporting coal and occasional passengers.[15]

While obtaining room and board in Halifax, Fleming began his search for a residence for his family (Fig 3). At the time, the city was undergoing a period of renewal, expansion, and rapid population growth – from 15,000 residents in 1841, to 30,000 by 1871.[16] A commercial rebuilding of the downtown core was also under way in the early 1860s (after large fires in 1857, 1859 and 1861).[17] Economically, Nova Scotia was the largest fish producer in British North America outside of Newfoundland, the mainstay being dried cod. The province's extensive mineral resources were also being mined. Over "Twenty-seven new collieries opened between 1863 and 1867," accounting for 15 per cent of the province's exports.[18]

## MARITIME UNION

By early spring (1864), local newspapers had been reporting that a Charlottetown Conference of Maritime premiers and "unofficial delegates" from the Province of Canada was being planned to meet

[15] The first public railway had officially opened in Canada in July of 1836 with the Champlain and St. Lawrence Railroad operations. A history of railway companies in Nova Scotia can be reviewed at Smith, Ivan. "History of Railway Companies in Nova Scotia." https://nshdpi.ca/is/rail/railways.html

[16] Buggey, S. (1980). Building Halifax 1841-1871. *Acadiensis 10*(1): 90-112. https://bit.ly/3Hx8DxQ (Accessed May 25, 2022).

[17] Ibid, 93.

[18] Conrad, Margaret. (2020). *At the Ocean's Edge. A History of Nova Scotia in Confederation*. University of Toronto Press, Toronto. p. 279.

**Fig 3 The first residence in Halifax for Sandford Fleming's family was at 2549-2553 Brunswick Street. Now designated as a HRM Historic Site and current location of Shelter Nova Scotia. Google Maps, 17 January 2022.**

in September to discuss Maritime Union. Two Canadians – the Irish born-Canadian politician, Thomas D'Arcy McGee, and his friend, now a Halifax resident, Scottish born-Canadian Sandford Fleming, both felt there was a need for delegates to get better acquainted in person before the September meeting, as both sensed there existed a degree of mistrust between the upper Canadians and downeast Maritimers.

Fleming had first met McGee in Toronto in the winter of 1861-62 when he heard him speak at a packed St. Lawrence Hall.[19] McGee had chaired an earlier Intercolonial Convention in Quebec, and strongly advocated for the construction of the Intercolonial Railway (ICR) line. He was no stranger to Nova Scotia either, having made four earlier trips to the province. "No Canadian politician knew more about the Maritimes, or more about Maritime politicians, than D'Arcy McGee … ."[20] By early August 1864, one hundred Canadians from the Province of Canada, including assemblymen, members of the Legislative Council, journalists, and other interested citizens, led by Thomas D'Arcy McGee and James Ferrier of the Legislative Council for the

[19] Wilson, David A. (2008). *Thomas D'Arcy McGee, Vol. 1, Passion, Reason, and Politics 1825-1857.* McGill-Queens University Press, Montreal.

[20] Ibid, 170.

Province of Canada, arrived in Halifax. For many in the visiting delegation it was their first trip to the Maritimes.

In Halifax, Fleming organized, with others, a long list of social festivities for the delegation, and "... as the banquets were held, the drink flowed and the music played, newspaper men in the company of prominent politicians and businessmen sent glowing reports to their reader back home."[21] The visit concluded with a great banquet for the Canadian visitors held on Saturday 13 August with the Honourable Joseph Howe as the last speaker. In essence, the "... the tour was in itself an exercise in the coming together of British America."[22] Many of the delegates would later get reacquainted at the Charlottetown Conference in September.

## THE START OF THE RAILWAY

On 4 February 1865, Fleming submitted information gathered by his survey crews in New Brunswick, outlining a number of possible routes for the ICR – 3 Frontier routes along the N.B./Maine border area (felt to be too close to the U.S. border); 9 Central routes through the middle of the province (which was still sparsely populated), and 3 Gulf routes following the northeastern Gulf side of the province to the Bay Chaleur (passing through a number of towns and Acadian villages). The before-mentioned Bay Chaleur route, first identified by Major Robinson in 1849, was ultimately selected as the best route. It continues today as the line traveled by CN and Via Rail. There were also six possible routes from Truro to the New Brunswick border that Fleming had identified from an earlier 65-page report by surveyor Francis Shanly on possible routes for a rail line.[23]

In March 1865, Fleming was still searching for a family home in Halifax and wrote to his ten-year old son Franky telling him how much he missed his family and that he was looking to let a house in

21 Wilson, David A. (2008). p. 203.

22 Creighton, Donald (2012). p. 95.

23 In January 1865, Francis Shanly had submitted a 65-page report and financial summary on survey routes and costs on the Truro to Moncton and Winsdor to Annapolis lines for C. J. Brydges of the Grand Trunk Railway, who had hoped to build the ICR. Due to no final commitment from provinces, Brydges decided he couldn't wait for the ICR to start and planned instead to extend his Grand Trunk line in Ontario to Chicago. He hired Shanly as Chief-in-Engineer. Sandford Fleming would later publish his perspective on the choice of a route through N.B. in *Report on the Intercolonial railway exploratory survey, made under instructions from the Canadian government in the year 1864. Printed by order of the Legislative Assembly.*

Halifax soon, hopefully "with a big yard for gardening."[24] In early 1866 Fleming finally found a house at 2549-2553 Brunswick Street in Halifax for his family. There, they lived until 1870 before moving to Ottawa.[25]

In early April (1865), news reached Halifax that General Robert E. Lee had surrendered his 28,000 Confederate troops to Union General Ulysses S. Grant, effectively ending the American Civil War. Only a few days later, tragic news also reached Halifax that United States President Abraham Lincoln had been assassinated on the evening of 14 April by a Confederate sympathizer, John Wilkes Booth, at Ford's Theatre in Washington, D.C.

By October 1865, while monitoring feedback on a possible route for the Intercolonial Railway (ICR) line, Fleming also began to express concerns to Premier Charles Tupper's provincial government about the time it was taking with various contracts to complete the 52-mile line from Truro to Pictou (including five Way Stations). He felt that if matters continued as they were, it was highly unlikely the line would be completed on time and on budget (expected to be 1 May 1867). It was during this time, on 4 October (1865), that Fleming also became a member of the Nova Scotia Institute of Natural Science.

While Fleming waited for his family to arrive in Halifax, he was authorized by Tupper's government to become the Chief Engineer on the Pictou rail project and to carry out what he thought would be the best action plan, within the budget's estimate (Fleming had quoted $2,116,500 = $32,561,538.46 in 2019 dollars) to complete the work. This was considered controversial at the time because Tupper had ignored the provincial statue that called for public tendering, Fleming nevertheless undertook the responsibility with vigor and confidence that came no doubt from his earlier experience of working for ten years (1852 to 1862) on the Northern Railway in Ontario.

On 28 February 1866, shortly after his family's arrival in Halifax, tragedy struck the Fleming family when three-month old son Paul Sandford died. Fleming wrote in his diary, "This morning about 4 o'clock after rallying a little … our dear child at last passed quietly away … . This is the first death that has really come home to me –

[24] Elliott, Andrew (2017).

[25] The first Fleming residence located on Brunswick Street near North Street was believed to be sold in 1873 after Blenheim Lodge was ready to move into. It is currently home to Shelter Nova Scotia.

part of us is now really in another world."[26] From his formative boyhood years, Fleming had maintained a lifelong Christian faith in the Presbyterian tradition.[27] Upon arriving in Halifax, he attended the newly opened St. Matthew's Presbyterian Church on Barrington Street (now St. Matthew's United Church, across from the Old Burying Ground). There Fleming developed a close friendship and kindred spirit with the Rev. George Munro Grant.[28]

On the 12 April 1867, the British government established the Canada Railway Loan Act, providing the terms of financial assistance for the overall construction and management of the proposed ICR. By 31 May 1867, the Truro-Pictou Landing rail line was completed as Fleming had promised in his contract. On that day, Fleming invited a large group of over 400 invited guests and officials to take the rail from Richmond/Halifax to Fisher's Grant in Pictou County to celebrate. He later published *Opening of the Pictou Railway, Nova Scotia. Observations, Correspondence, etc.*[29]

On 1 July 1867, the Confederation of the Dominion of Canada was formed. From Halifax, Fleming wrote in his diary, "Up at 5 o'clock, very cloudy and rainy … putting up flags etc. Clouds cleared away. Halifax very gay, a perfect sea of flags. Beautiful day. The demonstration went off splendidly."[30] On the 19 September 1867, Fleming's daughter Alice 'Maude' was born.

By December 1867, with British financial assistance in place, the Intercolonial Railway (ICR) line was officially created – in fact, its construction was a part of the terms of the British North America Act, 1867 (now referred to as The Constitution Act 1867). Fleming was appointed Engineer-in-Chief to oversee the construction

[26] Elliott, Andrew (2008).

[27] In 1879, Fleming would also publish *Short Daily Prayers for Busy Households*. See Burpee, Lawrence J. (1915) Sandford Fleming Empire Builder. Oxford University Press, Toronto. p. 152.

[28] Fleming would later invite Grant on his first western expedition through the Canadian Rockies between July and October of 1872, in which they would travel over 5,000 miles seeking a feasible rail route through the Rockies. Grant would go on to write a record of their adventures in *Ocean to Ocean* (1873), which became a best-seller. Later in 1877, Grant was installed as Principal at Queen's College (now Queen's University) in Kingston, Ontario. He and Fleming would cross the Rockies once again in 1883 – a trip that almost cost them their lives. Fleming would later be appointed as the Chancellor of Queen's in 1880, serving until his death in 1915.

[29] See The Online Books Page. https://bit.ly/42hMsUc (Accessed 2 May 2023).

[30] Elliott, Andrew (2008).

details for the rail line route that was chosen. It would be the Dominion of Canada's first national infrastructure project.[31]

Fleming established his office at 158 Hollis Street in Halifax and began immediately organizing the operational logistics for the ICR project. Covering over six-hundred miles, he first divided up the chosen route into four districts and than sub-divided them into twenty-five divisions, starting with, "A" at Riviére du Loup, Quebec and ending with "Z" in Truro, Nova Scotia. Each division was placed under a district engineer, responsible directly to Fleming. Resident engineers were appointed to each division, reporting to the district engineer, and each resident engineer had his "necessary" assistance."[32] The work would ultimately involve more than ninety engineers, thirty-two contractors with over 5400 men and boys working six days a week.[33]

In February of 1868, Fleming became a member of Halifax's North British Society which had over 400 members at the time, including his friend, the Reverend George M. Grant.

Later in April, while working on the ICR project, Fleming heard the disturbing news that his friend, Thomas D'Arcy McGee, had been assassinated on 7 April (1868) in Ottawa on the doorstep of the boarding house where he was staying. Shortly after, with the completion of the Truro-Pictou Landing rail project, and survey work continuing from Truro through New Brunswick, and still feeling the grief over the loss of their son Paul, and now the loss of D'Arcy McGee, Fleming wrote in his diary on 22 May 1868, "To England on S.S. *Washington* [with] Jeanie, Frank & Bob and baby (Maude)." It was a two-month holiday break of travel, visiting his birthplace in Scotland, and then later to Paris to visit the pavilion exhibits that were still displayed on the 1867 World Fair's Champ-de-Mars 172 acre site.

31 The ICR line connecting Halifax to Rivière du Loup, where it joined the Grand Trunk, was 902.84 km (561 mi.) in length. It was completed on 1 July 1876 at a cost of $35,000,000 (close to a billion dollars in 2023). It had a number of branches: a branch 32 miles long to Windsor, a branch 52 miles long from Truro to Pictou, a branch 11 miles long to Pointe-du-Chêne, a branch 89 miles long to Saint John, a branch 9 miles long to Chatham, and a branch, projected, 4 miles long to Dalhousie. For more detail see *The Intercolonial and the European and North American Railways, a Brief History*. At the blog: johnwood1946. https://bit.ly/3HBLiuT (Accessed 3 May 2023). The ICR operated until 1918 when it was folded into the newly formed Canadian National Railways (CNR).

32 Underwood, Jay (2011). Fleming's Army. Railfare DC Books, Pickering Ontario. p. 14.

33 Ibid. Appendix Four, "The Contractors." p. 205-207.

**Fig 4 Fleming's Ottawa residence which he named Winterholme. Photographer William James Topley. Library and Archives Canada, William James Topley Collection, PA-026478.**

Back in Canada, D'Arcy McGee was later given a state funeral in Montreal in one of the largest funerals ever held in the country, attended by an estimated crowd over over 80,000 (in a city of 105,000). Sadly, on their return trip to Halifax, the Fleming's 10-month old daughter, Maude, died on 16 July.[34]

## BACK TO OTTAWA AND RETIREMENT

In 1869, Fleming purchased a residence in Ottawa that he named *Winterholme* (Fig 4) and moved his family there from Halifax to be closer to the political decision-makers concerned with construction of the ICR and where he also knew there would be emerging plans for a railway to the Pacific. Fleming's son, Walter 'Arthur,' was born in October 1869.

While residing in Ottawa in the spring of 1871, Fleming was appointed Engineer-in-Chief for the proposed Canadian Pacific Railway (CPR) by Prime Minister John A. Macdonald's federal Conservative government. British Columbia was planning to join confederation in July and the promise of a railway had been written into the agreement

[34] Reported in the *Presbyterian Witness*, 26 July, 1868. Death was also recorded in the *N.S. Registry of Deaths* on 29 July 1868, aged 10 months (b. 19 Sept. 1867) – also reported in the *Halifax Reporter*, 1 Aug., 1868.

**Fig 5 Blenheim Cottage, South End, Halifax. Though not credited, the gentleman standing to the right is believed to be Sandford Fleming. c. 1873, Royal Engineers. Nova Scotia Archives. Number 7029 (Piers 75)/negative N-1455.**

Fleming was expected to start work immediately on identifying preliminary routes to the Pacific, with an expected completion by 1881 (he also remained Engineer-in-Chief of the Intercolonial Railway for five more years).

The railway through the Rockies to the Pacific would later become an engineering marvel, making the ICR project look like a stroll in the park. Through it all, Fleming's connection to Halifax remained strong as a result of his purchase of 260 acres of land in 1870 on the western side of the Northwest Arm known as the Dingle Lands property.[35]

Early in 1872, Fleming purchased a summer residence on the eastern side of the Northwest Arm, in the south end of Halifax off Oxford Street, that he named *Blenheim Cottage* (Fig 5). It was where he and

[35] After dividing some of the Dingle Lands into lots for his family, Fleming donated 100 acres to the Nova Scotia Lieutenant Governor in Trust for City of Halifax in 1908 and commissioned the construction of a Memorial Tower in 1908 for the 150th anniversary of representative government being established in Nova Scotia (1758-1908). On 14 August 1912, the lands officially became known as the Sir Sandford Fleming Park. An excellent overview entitled "Sir Sandford Fleming Park and the Memorial Tower: A Brief and Not at All Definitive History," can be located on the Halifax Public Libraries' web site. https://bit.ly/3ALSrEP


**Fig 6 An Intercolonial Railway poster. Public domain.**

his family spent many of summers and where he "retired" following his knighthood in 1897.

Later in that summer of 1872, Fleming organized his first five-member expedition west to determine the best route for the railway that Sir John Macdonald had promised British Columbia.[36] The expedition started in July from Toronto with a plan to cross the Prairies and through the Rockies. They traveled 8,552 km (5,314 miles) by horses, wagons, canoe and by foot, arriving in Victoria, B.C. on 9 October. Besides his son Frank (16), his good friend, the Rev. George Grant, also accompanied them as secretary to the expedition and wrote a book the following year that became a bestseller, detailing the experiences of their journey called *Ocean-to-Ocean, Sandford Fleming's Expedition Through Canada in 1872.*

On 1 July 1876, the ICR line was completed allowing for passenger rail service from Halifax to Quebec (Fig 6).

[36] In June 1883, Fleming received a telegram from George Stephen, President of CPR, asking him to head to British Columbia to review A.B. Roger's survey work to determine a usable pass through the Selkirk Mountains. By August he began his second expedition west. The Revd. George Grant would accompany him once again, as did his sixteen year old son, Sandford "Bob" Jr.

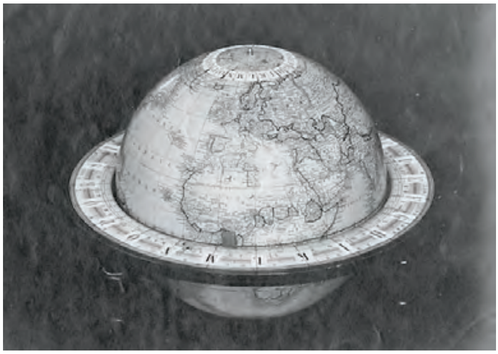

**Fig 7 Sandford Fleming's Globe, 1885. Notman Studio. Nova Scotia Archives. 1983-310 number 5421.**

Exhausted from the work of being both the Engineer-in-Chief for the ICR, as well as for the proposed Canadian Pacific Railway (CPR), Fleming took his family to Europe that summer for a rest and vacation. It was on that trip, when he had missed a train in Ireland due to time schedules, that led to his model for the creation of the world's time zones which he first proposed in February 1879 at a meeting of the Royal Canadian Institute entitled *Time-reckoning and the selection of a prime meridian to be common to all nations.* It outlined his formative ideas for a global model for standard time zones set to a subordinate single world time (Fig 7).

**Fig 8 Lord Strathcona, the Honourable Sir Donald A. Smith, laying the Last Spike for the completion of the transcontinental CPR railway on 7 November 1885. (Courtesy Alexander Ross/Library and Archives Canada – C-003693)**

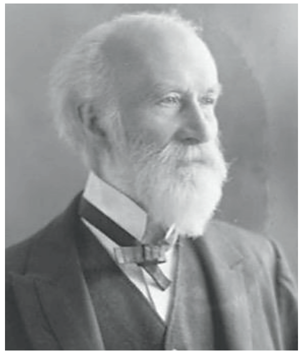

**Fig 9 Sir Sandford Fleming, April 1902. Photographer, William James Topley. Topley Collection, Library and Archives Canada.**

In 1882, Fleming became a founding member of the Royal Society of Canada. Besides advocating for a model of time reform, it was during this time that he also began to advocate for a trans-Canada undersea telegraph cable link from Britain, across the Pacific to Australia and New Zealand, known informally as the *All Red Line*. It had been a dream of Fleming's since the first trans-Atlantic cable occurred in August 1858 from Newfoundland to Ireland. When it was completed in 1902, Fleming was regarded as the father of the Pacific cable scheme.

In 1883, Fleming conducted a second expedition across the prairies and through the Rockies. A year later, his global model for standard time zones was accepted at the Prime Meridian Conference in October 1884 (attended by twenty-six countries), becoming one of the greatest achievements of standardization in the nineteenth century.

The following year (1885), Fleming (age 58) appeared at the very centre of the iconic "Last Spike" photo taken at Craigellachie, British Columbia on 7 November, seen wearing a large top-hat to witness Lord Strathcona, the Honourable Sir Donald A. Smith, laying the last spike for the completion of the transcontinental CPR railway (Fig 8). By that time, Fleming was also a director of CPR.

Four years later (1888), Fleming was widowed when his beloved Jeanie died while visiting their daughter in France. Knighted in 1896, Sir Sandford Fleming (Fig 9) lived to 88, dying of pneumonia in Halifax on 22 July 1915 while on a summer visit to his daughter Minnie and her family at the Dingle cottage, across the Northwest

Arm from his own beloved Blenheim Cottage. He was later buried at Beechwood Cemetery, Ottawa.

In 2023, Fleming's legacy of universal standard time is now why we can look at our watches and calculate time on the far side of the earth. If he were alive today, no doubt he would thoroughly relish being involved in the debate on a global model for establishing Lunar Time!

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# RON O'DOR: A LIFE OF JOY IN SCIENCE

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Dr. Ron O'Dor, a distinguished Department of Biology faculty member at Dalhousie University and member of the NSIS, passed away on May 11, 2020, a victim of the COVID pandemic that has shaken the world for three years.

Ron was born in Kansas City, Missouri, and his career spanned the fields of biochemistry, physiology and marine biology, with specialties in cephalopod biology and aquatic animal telemetry. He completed his undergraduate degree in biochemistry at the University of California Berkeley and his PhD in salmon calcitonin physiology at the University of British Columbia. After a postdoctoral fellowship split between Cambridge University in the UK and the Stazione Zoologica, Naples, Italy, Ron took up a faculty position in Biology at Dalhousie University in 1973. He was Director of Dalhousie's Aquatron Laboratory from 1986-1993, Chair of the Biology Department from 1997-2000, and held short-term positions of Visiting Researcher/Scientist at various universities in Canada, the USA, Australia, China, France, Japan, Papua New Guinea, Portugal, and South Africa, until he became Emeritus Professor at Dalhousie upon his retirement in 2015.

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Ron made immense contributions to cephalopod ecology and physiology, achieved by using a suite of interdisciplinary techniques including behaviour and ecology, physiology and innovative telemetry tracking techniques. He was an ecophysiologist long before the term became popular. His lab was always filled with repurposed scientific equipment tied together with wire and plumbing bits. In fact, for a time there was a "MacGyver Award" (named after the TV show hero who was always cobbling things together to save the day) in the Dalhousie Biology Department, but the award was eventually retired because Ron was in almost permanent possession of it. One of his quests was to understand movements and jet propulsion in squid and he famously published papers such as the "Choreography of the squid's nuptial dance" and "The incredible flying squid" (Fig 1).

When the Census of Marine Life (CoML) – a 10-year international effort undertaken to assess the diversity, distribution, and abundance of marine life – formally launched in 2000, the breadth and depth of Ron's interests and sense of humour made him the winning candidate for the post of Chief Scientist. He moved to Washington DC to take on this role from 2000-2010. In this role Ron did an outstanding job in recruiting, stimulating, and connecting scientists globally, and in communicating results from the CoML. Out of the CoML grew a dream of Ron's: the idea to build a global network of acoustic receivers and oceanographic sensors in all the ocean regions of the world to

**Fig 1 Ron at sea, with one of his beloved squid.**

**Fig 2 The early days of acoustic telemetry of aquatic animals: Ron deploying a pole-mounted acoustic receiver listening for the animals he had tagged.**

track keystone, acoustically tagged animals along migratory routes (Fig 2). This led to the birth of the Ocean Tracking Network (OTN), headquartered at Dalhousie University and launched as a Canada Foundation for Innovation International Joint Venture Project in 2008. Today the OTN is a global research, conservation and infrastructure platform and one of Canada's National Research Facilities, focused on understanding aquatic animal movements and survival in relation to changing environments in order to enable better stewardship of the world's aquatic resources. OTN has been foundational to the birth and growth of other major oceans initiatives and research at Dalhousie University. For his work with the CoML and the OTN Ron was named Canada's Environmental Scientist of the Year by Canadian Geographic in 2009.

Ron was a valued mentor to students, postdoctoral fellows and other trainees. He was known for encouraging students to visualize the puzzle as a whole before trying to put the pieces together, and to learn the importance of resourcefulness – the ability to take the tools you have at your disposal and adapt them to solve a problem at hand. One past student described how the defining moment of their research career came when, after much pondering and discussion of how they could study the relative roles of hydrodynamic drag and gravitational forces in the feeding and swimming dynamics of larval scallops, Ron saw a Request For Proposals from the Canadian Space Agency for work to be carried out on the NASA space shuttle. One successful proposal later, a group of scallop larvae were blasted

**Fig 3 Always ready to talk, Ron was constantly sharing his insights in classrooms and with audiences worldwide.**

into space where the impact of hydrodynamic drag could be studied in the absence of gravity. It was another Ron moment where a tool was adapted by a resourceful mind for an unconventional purpose: “Scallops in Space”.

With students and colleagues alike Ron was extremely social, enthusiastically exchanging ideas and jokes with a smile and clap on the shoulder (Fig 3). Ron is remembered by his colleagues for his big ideas on big science, the use of cutting-edge technologies, for his ready smile and laugh, for his inventiveness worthy of MacGyver, and for his kindness and humanity. Former students fondly remember that Ron was kind, gentle, smiled all the time, could speak on an incredible breadth of topics, and always wore a suit jacket with his signature turtleneck. Everyone remembers that Ron did not have any hobbies and never took a vacation. As far as Ron was concerned his career of travel and visiting exotic places made them redundant.

Upon his passing, Ron left behind his loving companion Janet, who tolerated his idiosyncrasies and brought out the best in him for 52 years. He also left two children, and four grandchildren. For those of us in the science community who knew him as a colleague, teacher and friend, with his passing the world became a bit dimmer, and science a little less fun, than it was just before.

Dr. O’Dor is being recognized and honoured with a nomination for the NSIS Hall of Fame.

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# ALAN RUFFMAN: A NOTED NOVA SCOTIA SCIENTIST AND ACTIVIST

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Long time NSIS member Alan Ruffman passed away suddenly on December 28th, 2022, at the age of 82. Alan was well-known as a community activist in Halifax and as a geoscientist with interests not limited by conventional disciplinary boundaries. Much of his science was carried out under the umbrella of his consulting company, Geomarine Associates. He was known to the press, documentary makers and the public not only for his activism on urban planning, but also for his work on earthquakes, tsunamis, and the geoscience and other aspects of the sinking of the Titanic and the Halifax explosion. He was the local go-to person for the press for questions about earthquakes, and his statements were always meticulously careful and accurate.

As an undergraduate at the University of Toronto (1959-64), Alan had summer field experience in the Canadian Shield. At that time, he also crossed the stormy Atlantic in a freighter and decided he wanted to be a marine geologist. Attracted by the presence of the Bedford Institute of Oceanography and the chance to sail on the *CSS Hudson*, he came to Dalhousie University in the fall of 1964 with an NRC scholarship to do a Master of Science degree.

Alan's first important geoscience contribution to public policy, in 1971, was to recognize the significance of Orphan Knoll in the southern Labrador Sea, which from its bathymetry seemed to be a continental fragment like Flemish Cap. He understood how important Orphan Knoll would become in defining the outer limits of Canadian jurisdiction over the seabed. Remarkably, he found himself in a position to influence where Leg 12 of the Deep Sea Drilling Project

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would drill adjacent to Canada, and succeeded in getting approval for a drillhole on Orphan Knoll. He also got himself on the *Glomar Challenger* as a participant on the Leg. It was Alan who named the Knoll as an orphan, left behind as Europe separated from North America through continental drift. The continental sediments of Jurassic age recovered at the bottom of the drillhole were perhaps more like those known in Ireland than in Canada. He maintained an interest in the geology of Orphan Knoll throughout his career, contributing to his last journal paper on the Knoll in 2020.

Alan and John Stewart founded the consulting career and contributed to Geomarine Associates Ltd. in 1973, carrying out pre-drilling site surveys on the Canadian offshore. They were involved in the 1979 discoveries of the Venture gas field, Hibernia oil, and Labrador gas. Geomarine soon out-competed foreign companies and by 1982 had 32 staff with offices in St. John's and Halifax. In 1985, the company divided: Alan took the name and library and worked on his own; John took the staff. Alan was always interested in doing science with site surveys. At that time, exploration concerns included severe shallow overpressures, unknown shallow stratigraphy and sea-level history, and active seabed sand migration. Geophysical data collection, borehole investigation and seabed charting are documented in the company's countless technical client reports, providing interpretations of the shallow geology of the offshore Scotian Shelf around Sable Island.

In the 1990's, Alan discovered and mapped the sediment layer on the Burin Peninsula produced by the 1929 tsunami (Fig 1); he recorded oral histories of the event. This early work was very influential for the thorny question of distinguishing tsunami from storm deposits and gained Alan international recognition. Alan became interested in paleoseismicity as reported in historical records, for example discovering that the tsunami created by the 1755 Lisbon (Portugal) earthquake reached the coast of Brazil. His forensic skills in scientific and historical research were applied to the Halifax explosion and the tsunami it produced; the sinking of the *Titanic*, the rescue effort from Halifax, and the identity of the unknown child; the impact of the Saxby Gale; and the history of ice in the Gulf of St Lawrence. He wrote a well-regarded popular book, *Titanic Remembered: The Unsinkable Ship and Halifax*, on the sinking. He was an accomplished communicator who made our marine geology and history well known internationally, through the press, television and his

**Fig 1 Alan Ruffman in 1994 with an overturned sod showing the 1929 sandy tsunami deposit (light colour) in the coastal marsh peat (dark) on the Burin Peninsula, Newfoundland. Photograph courtesy of Martitia Tuttle.**

writings. Indeed, he was identified as a Halifax "historian" by the *Washington Post*.

Alan did not forget his early experiences on the Canadian Shield. In the 1980's, he promoted the study of what he termed the "Weekend Dykes" on the Eastern Shore near Tangier, so named because he could only take time off work to study them at weekends. Like dykes on the Canadian Shield, these igneous rocks contained an important record of the lower crust beneath the Meguma terrane. And his last great enthusiasm in 2023 was new evidence for post-glacial activity on the "Holy Grail Fault" in the muskeg of north-central Manitoba, analogous to the well known post-glacial faults of Scandinavia.

Alan was a talented polymath who developed and promoted advancement of marine geoscience, and throughout his long career he made new findings clear to the general public. He was endowed with a deep curiosity, was sometimes irritatingly meticulous and loquacious, but had a sharp mind able to identify important opportunities. His work is widely known and influential both nationally and internationally, a remarkable achievement for someone who did not have a university, government, or corporate employer to pay his expenses. He was always a perceptive, kind and generous supporter of the under-dog, be whether they were students or under-appreciated scientists. He himself was under-appreciated because of his idiosyncrasies, but he was always there for others. He will be greatly missed in Nova Scotia and beyond.

## SELECTED PUBLICATIONS OF ALAN RUFFMAN

(This list is in chronological order, starting from the most recent)


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**Note**: According to his short unpublished autobiography, Alan had 122 "refereed or semi-refereed" published items; authorship of 163 *Geomarine Associates* contract reports, most of which are now public; 201 abstracts of public scientific talks; 15 book reviews; and 104 "other" published articles.

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# ARBORETUM NOVA SCOTIA: TITUS SMITH JR.'S *OBSERVATIONS OF THE NATURE AND USES OF TREES*

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## ABSTRACT

The focus of this essay is Smith's unpublished manuscript on the *Observations of the Nature and Uses of Trees* that he attached to the final report of his 1801-1802 colonial surveys tabled by the treasurer Mr. Michael Wallace in the Nova Scotia House of Assembly on 9 March 1802. The existence and importance of this unpublished manuscript was noted on 26 June 1866 at the Field Meeting of the Nova Scotian Institute of Science held at Ashbourne. Smith uses common names and Linnaeus's taxonomic system of classification to identify and describe the distribution, habitats, and European and Indigenous uses of specific tree wood, bark, leaves, and fruit.

## INTRODUCTION

Over two hundred years ago in 1802, Titus Smith Jr. [1768-1850] returned from his government sponsored journeys into the relatively unknown interior of Nova Scotia (Field 2020: 351-361) captivated by the lure of the deep Acadian forest (Loo & Ives 2003: 462-463). The majesty of a variety of imposing trees, and his encounters with multitudes of plants, birds, insects, mammals, and reptiles living between the forest canopy and the forest floor in a thriving ecosystem grounded his insights about the relationship between humanity and the environment, and inspired his Theory of Ecological Succession (Gorham 1955: 116-119). Thirty-three years later, on the evening of 14 January 1835, when Smith presented his most important lecture to the members of the Halifax Mechanics' Institute on the "Natural History of Nova Scotia," he was still in awe of the colony's forests (Field 2019: 118-123). "For, rough and rude as our forests appear, they form a portion of the 'garden of God.' In all their various productions, there is nothing superfluous or out of place. The student of natural history in America possesses one advantage over the inhabitants of

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its mother country. He has under his eye tracts where the works of nature have not been disturbed by man" (Smith 1835: 642).

## THE ACADIAN FOREST

Smith, however, was not the first explorer/naturalist to extoll the majesty of the Acadian landscape. Sailing along the sandy-red coastline of Prince Edward Island during his first voyage in 1534, Jacques Cartier [1491-1557] drew attention to vegetation and animal life that was surprisingly similar to that of France. By his third voyage in 1542, he was absolutely demonstrative about the richness of the soil that produced vines heavy with grapes and mulberries, while the oaks, cedars, and beeches he found fairer than those in Europe (Cook 1993: 22-23).

Less then a hundred years later, the grandeur of the Acadian forest and the natural bounty and richness of its soil also deeply impressed Richard Guthry. In the summer of 1629, the Scots established two colonies in Nova Scotia, the first on Cape Breton Island, which the French destroyed a month later (Nicholls 2005: 109-123), and the second at Port Royal, which reverted to French control under the terms of the 1632 Treaty of Saint-Germain that re-established their claim to Acadia. Providing for the first time reliable documentation about a previously obscure colonial enterprise, the manuscript firmly established the importance of the New Scotland Colony at Port Royal during the first decades of the seventeenth century (Griffiths & Reid 1992). Unfortunately, historical information about the author is frustratingly unknown, although Guthry's baptism of a boy in Newfoundland tantalizingly points to a life in the clergy. Guthry felt obliged to begin his narrative by thanking an unnamed benefactor. "It pleased your honour at my departure from England to lay a charge upon me, to writt a particular relation of our Voyage at Sea and of the nature and condition both of people and Country" (Griffiths & Reid 1992: 500).

Guthry successfully accomplished this request by providing personal observations and descriptions about the geography, natural history, and Indigenous peoples of the region. He also commented on the magnificence of the woodland landscape surrounding Port Royal. "Fruitfull vallies adorned and enriched with trees of all sorts, as goodly oakes, high firres, tale beich and birch of incredible bignes, plaine trees, Elme, the woods are full of laurall store of ewe, and a great variety of fruit trees" (Griffiths & Reid 1992: 503). Like Cartier, he also remarked on the richness of the soil and recognized wild herbs, and roses similar to those cultivated in England. At Port Royal he stated, "The land is most fertile: for I myself caused dige and hedge a garden platt of sixty foot in length and thirty in breed, and sowed onions, cabbage, turneps, carrets, sorrel, parsneps, Radishe, pise, and some barley to make a tryall, and to our admiration we had them above ground, some in tuo, some in three, some in four dayes, though it was a dry Season, not having rained a moneth, and being the latter end of August" (Griffiths & Reid 1992: 504).

Guthry used Eden like language common to other explorers who described the forested landscapes from Acadia to Quebec. For example, while at Quebec, Pierre-François-Xavier de Charlevoix [1682-1762] remarked that "Nothing is more magnificent to the Sight; the Trees lose themselves in the clouds; and there is such a prodigious Variety of Species" (de Charlevoix 1766). Throughout the document, like Smith, Guthry echoed Francis Bacon's [1561-1626] opinion that nature is a storehouse of raw material benevolently bestowed by God on humankind during creation. Guthry expressed in his buoyant writing style that through God's grace the fertile land produced "… a rich crope of whatsoever we trust to the earth" (Griffiths & Reid 1992: 504).

## THE NATURALIST'S FIELD JOURNAL

One would have thought that by the end of the eighteenth century the enchanting allure of Nova Scotia's Acadian forest would have faded, and that the knowledge about the natural history and resources of the woodland interior was more or less known, but that was not the case. Surprisingly, by 1800, the inland waterways, and lakes, forests, rivers, and mountains of Nova Scotia still remained largely unexplored by Europeans until Lieutenant Governor Wentworth [1737-1820] commissioned Titus Smith Jr. to survey the interior parts of the colony [Nova Scotia became a province in 1867].

In a letter dated 2 May 1801 [Appendix 3], Wentworth outlined instructions for Smith to conduct surveys of the Eastern and Western interior parts of the colony and to communicate his findings in the form of a journal. Wentworth's orders to Smith were explicit. "Your principal object in this survey will be to visit the most unfrequented parts, particularly the banks and borders of the different rivers, lakes, and swamps, and the richest uplands, for the purpose of discovering such spots as are best calculated for producing hemp and furnishing other naval stores" (Lawson 1972: 209). In addition, Wentworth instructed Smith to evaluate the soil, portray the landscape, determine the species, size, and quality of timber, and estimate the number of acres suitable for cultivation. Smith also was to record topographic details and correct local place-names on the poorly drawn existing colonial map. Two factors prompted the government to finance these journeys. First, the geography and natural history of the interior was mostly unknown. Secondly, following the loss of the American colonies, the Admiralty looked to Nova Scotia to find new sources of naval supplies and questioned Wentworth about ascertaining the ready accessibility of mast-grade pine, deck timbers, wood suitable for ship's knees, and appropriate sites for growing hemp used in manufacturing canvas and rope (Gwyn 2001: 5,8,13).

Smith accomplished his commission as Wentworth requested by communicating his findings in journals. Just as the documentation attached to botanical specimens found in historical herbariums identify the collection of plant species in space and time, so do the field journals of naturalists. The journal is a primary source that makes fieldwork empirical through quantitative measurement and qualitative analysis. Smith's two original leather-bound journals from his 1801 and 1802 Eastern and Western surveys of the interior of the colony, measure 4 x 6 inches and 3 x 7 inches respectively (Field 2020: 361-362). Both journals, which would have fit neatly into Smith's breast or back pocket, are not specific to these journeys, but were also used to record observations related to other fieldwork. For example, the notebook of his Eastern Tour covers a period of 35 years, from 1801 to 1836. Noteworthy is Smith's sometimes-shaky handwriting emphasizing the first-person narrative of his note taking. Importantly, Smith often augmented his initial observations with annotations in the page margins of his journals, and recorded his personal observations and reflections on colonial society, giving accounts ranging from the farms and communities he encountered, to the plight of the Mi'kmaq.

As Cathryn Carson pointed out, "… the field notebook or journal, sits at the crossroads of literary subjectivity and methodological objectivity, re-marking an interaction of the humanities and science" (Carson 2007: 6). Thus, using primary historical sources such as field journals in ecological studies can create various degrees of complexity (Tappeiner *et al.* 2020: 2318). They can be compromised by the training of their authors, undermined by contrasting tendencies towards generality versus particularity, mismatched in the scale and precision of data collection, damaged or incomplete, or hampered by differing spatial and temporal frames of reference, particularly before 1800 (Pooley 2013: 1481).

Szabó and Hédl elaborate "… most differences stem from miscommunication between ecologists and historians and are less substantial than is usually assumed. Cooperation can be achieved by focusing on the features that ecology and history have in common and through understanding and acceptance of differing points of view. We argue that historical ecological research can only be conducted at extents for which sources in both disciplines have comparable resolutions" (Szabó & Hédl 2011:680). For Pooley, "… this lack of ecological data is really an opportunity for ecologists to gain from history" (Pooley 2013: 1481, Szabó & Hédl 2011: 685). Pooley's point is well taken. Problems arise when the relationship between the two disciplines is too broadly framed. Very specific historical sources, such as species lists, journals, diaries, illustrations, collections of flora and fauna, and correspondence have proven invaluable in which Smith's observations recorded over 200 years ago about the nature and uses of Nova Scotia's forest reserves is a case in point.

## FOREST COMPOSITION

As Smith traversed the interior of mainland Nova Scotia "… with an eye out for good pine, Smith classed the lands he saw by the value of their timber as "burn" or "barren," both of which he estimated at over a million acres" (Leeming 2012: 54). Smith described the "barren" tracts of land as the principle source of our brooks and rivers, as the solid rock of which they are comprised are incapable of absorbing the water like the earth, noting that some parts of the barrens that appear to be loose broken stone, commonly have solid rock a few feet below the surface, and the barren valleys of loose broken stone, which have water within them three or four feet from the surface, frequently have a thick growth of Spruce and Fir, 30 or 40 feet high (Smith 1835: 652-658, Hawboldt 1955).

However, when discussing the "burns" caused by nature or by the deliberate torching of the woodlands by humans, Smith was clearly concerned about the role that colonists played in initiating these blazes:

> "The great influx of inhabitants in 1783, produced in the course of a few years, a complete change in the appearance of the forest. A great number of new settlements were formed. The fires necessary for clearing the land were communicated to the spruce thickets, and spread frequently as far as they extended. The profusion of herbage which followed the fire, for a time furnished a pasture for cattle. This failed in three or four years. The next dry season the fire was rekindled, for the purpose of renewing it, which it would do in a less degree. Raspberries, French willow, and other vegetables would appear upon part of the ground, but of inferior growth. The roots of the spruces and balsam fir spread horizontally, and take but slight hold of the ground. Being loosened by the sinking of the turf, they are overthrown by every wind, and furnish fuel for successive fires, which are usually rekindled every dry season by design or negligence till…the ground becomes so much exhausted, that it only produces a growth of healthy shrubs" (Smith 1835: 651).

It was during these colonial surveys for Wentworth that Smith began to record in his journals changes he observed in the landscape caused by profound natural or human disturbances, which is expressed in his classification of the land as "burn" or "barren." Some of these very formative ideas, which eventually became the basis of his Theory of Ecological Succession (Gorham 1955: 116-119, Smith 1835: 645-657), are also found in his comments about the habitats of the trees he discussed in his manuscript on the *Observations of the Nature and Uses of Trees* [Appendix 1]. For example, in entry 2 [White Pine/*Pinus strobus* L.] he noted, "It grows naturally in every kind of barren soil, whether wet or dry. It is to be found in all rocky barrens, but it is there so short and scrubbed as to be of no value. The best pine is to be found on a sandy soil, which is not very rocky, or very near the sides of lakes." While in entry 11 [White Birch/*Betula papyrifera* Britt.], he stated "This tree always forms the principal part of such forests as grow up when the original growth of Timber has been destroyed by fire provided the soil is not extremely barren."

When Smith arrived in Nova Scotia with other Loyalists escaping the American Revolution in 1783, he was only 15 years old. Eighteen years later, he was journeying through the interior of the colony for Wentworth. Thus, as early as 1801, Smith began to understand that nature was not a closed system and that disruptions to ecological communities, whether caused by natural or human events, resulted in new associations between species. The point here is that it took Smith over three decades to formally present his ideas about recurring changes in nature, which he did on 14 January 1835, in the second of two public lectures before the Halifax Mechanics' Institute [1831-1862]. This landmark presentation delineating the natural and human forces behind the process of plant dispersal and succession was subsequently published in the December issue of London's *The Magazine of Natural History* as "Conclusions on the results of the Vegetation of Nova Scotia and on vegetation in general, and on man in general, of certain Natural and Artificial Causes deemed to actuate and Affect them" (Smith 1835: 641). The very title itself lays out Smith's continuing concerns about how disruptions to the natural environment impacted species composition. For example, with regard to forest communities, "Smith remarked that the hardwoods, dominated by beech, occur mainly on the hills, where also the best soils are found. His explanation is that the frequent fires in the lowlands allow nutritive products of organic decay to escape into the air, whence they are blown to the hilltops where the hardwoods absorb them. Probably the burning did have an effect through keeping the communities at an early stage of seral development; and of course the impeded drainage of the lowland causes much of it to be covered with spruce and larch bog …" (Gorham 1955: 120).

For Smith, human caused fires were the most important instigator of these changes, first by destroying the existing symbiotic relationship between species, which often created "barren" land, or by renewing it to provide conditions for a new palette of species to flourish, particularly after the spring rains swept down across the fire-blackened earth turning it a light green. This same conclusion was also reached in the *Nova Scotia State of the Forest Report 2016*, which stated that, "… most fires are caused by humans and the greatest number occur in spring" (Nova Scotia Natural Resources 2016: 1). Smith elaborated on this process. "The naked black surface is now exposed to the sun, and the process of putrefaction commences in earnest, affecting the turf as well as the roots of the vegetables which have been killed by the fire. The increased temperature of this natural hotbed brings into action the vegetative powers of seeds which had lain dormant for centuries; raspberries spring up in abundance, together with red-berried elder, birdcherry, sumach, prickly aralia, and evergreen fumitory" (Smith 1835: 646). However, Smith also pointed out that "… from the time that a growth of young wood, springs up, till the forest has reached its full size, the ground that it covers is becoming everyday more fertile; but when the wood is destroyed, and prevented from returning … it is for many years constantly becoming more barren …." (Smith 1835: 642).

While Smith did comment on other natural disturbances such as the "blowdowns" he witnessed north of St. Margaret's Bay when miles of trees were blown over during the great storm of 25 September 1798 (Taylor *et al.* 2020: 390), he was more vexed by the extensive damage caused by wildfires to forest ecosystems. On 09 July 1801, one day after leaving on his Western Tour towards St. Margaret's Bay on the foot-way from Dutch Village, he wrote in his journal, "For about 3 Miles from the Bay, the timber has been destroyed by fire; above that, it is chiefly spruce, hemlock, and pine with very little hardwood in some places" (Hawboldt 1955). On 15 July near Gold River, he wrote, "… the land after we passed the first river has had the timber destroyed by fire, probably 30 or 40 years ago, and is covered with a young growth (Hawboldt 1955). Finally, reaching Shelburne on 01 August he remarked "… many of the Hills near Shelburne would produce good Pine were it not that Fires are so frequent that it does not get time to grow" (Hawboldt 1955). Smith was also informed about a massive fire that occurred in 1720, which destroyed over 150,000 hectares of forest in Queens and Lunenburg counties (Taylor 2020: 390-392).

It is therefore not surprising that similar devastating fires were also recorded in the historical records of other explorers and settlers. Nicolas Deny [1598-1688], who arrived at present day La Have in 1632, reported in his *Description and Natural History of the Coasts of North America (Acadia)* published in 1672, "… that sometimes from spring to autumn, thunder strikes in the woods can cause fires that last three to four weeks unless rain falls, which can burn 10 to 15 leagues [50 to 75 km] of country" (Taylor *et al.* 2020: 390, Deny 1672). In 1800, Simeon Perkins [1735-1812], who settled in Liverpool in 1762, as part of the New England Planter migration to Nova Scotia, recorded in his diary a fire south of Lake Rossignol that burned an estimated 175,000 hectares (Taylor *et al.* 2020: 392). As Leeming noted, "Smith's reports, emphasizing the large acreage of potential forest wealth lost to fire, is the first clear documentary link between the state's involvement in the scientific measurement of available resources, the regulation and promotion of their use, and the prevention of wastage through fire" (Leeming 2012: 54). Consequently, Nova Scotia's woodlands have undergone a long history of clear-cutting, timber harvests, human and naturally caused fires, and the introduction of non-indigenous invasive species that have all altered the age and historic composition of Nova Scotia's forests (Taylor *et al.* 2020: 390).

As a result, "… Nova Scotia's forests today are, on average, younger, and more fragmented, and the trees of smaller stature than recorded in the comments by Smith. There is also an altered tree species composition" (Taylor *et al.* 2020: 390). All this is evident from Smith's information on the primary tree species of the colony. For example, Beech is suggested by Smith as one of the species dominating the hardwood forest of Nova Scotia, which "… forms the greater part of the Woods in our best land …" [Appendix 1, entry 13]. More recent inventories suggest Beech forms a much smaller component of the forest, now superseded by Sugar Maple and Yellow Birch (Townsend 2004). This decline in the proportion of Beech may be due to the impact of the invasive alien Beech Bark Disease which has devastated Beech in many areas (Farrar 1995). Another species devastated by an alien fungal disease is the American Elm affected by Dutch Elm Disease (Farrar 1995). However, Smith indicates even then Elm was rare. Recently, it was not found in any of the 3,250 random plots placed in Nova Scotia forests (Townsend 2004). Overall the composition of the forest has changed since Smith's inventory, probably, in large part, the result of tree harvesting over the last 200 years. The principle species listed by Smith include white and red pine, hemlock and sugar maple. Today, Balsam fir, Red Maple and Red Spruce are the most dominant species in Nova Scotia (Townsend 2004). The long history of tree harvesting since Smith's report is likely the most significant cause of the dominance of Red Maple and Balsam Fir because these species frequently dominate cut areas, post harvest, in Nova Scotia (Stewart and Quigley 2000). With a changing climate, continued exploitation of timber and the introduction of new alien pests [e.g. Emerald Ash Borer and Hemlock Wholly Adelgid], the future structure and composition of Nova Scotia forests is uncertain. Smith's study provides one benchmark with which to measure future changes to the forest of Nova Scotia (Cameron R. (2023, pers. comm.).[1]

## SMITH'S OBSERVATIONS OF THE NATURE AND USES OF TREES

At the previously mentioned Nova Scotian Institute of Science meeting on 26 June 1866, the President J. Mathew Jones noted in his introductory remarks not only the significance of Smith's manuscript, but also the fact that he worked on it while conducting his government journeys. "Being employed in different provincial surveys in the interior he had ample opportunity of pursuing his favourite study, and made such good use of his time while in the forests of these expeditions, that he was enabled to write a concise history in manuscript of Nova Scotia Forest Trees and Shrubs, which contains much valuable information" (Jones 1867: 149-150), Field 2020: 354-361).[2]

In Smith's never before published *Observations of the Nature an Uses of Trees* [Appendix 1], Smith describes the distribution, habitats, and European and Indigenous uses of specific tree wood, bark, leaves, and fruit, which also included a separate *List of Trees* [Appendix 2] that was previously published by Andrew H. Clark (1954: 308-310) and Evile Gorham (1955: 122-123). Smith's Latin designations are based on his ownership of Linnaeus's *System Naturae* [1758], which was gifted to him by Governor Wentworth, and according to Harry Piers, marked "… the commencement of scientific taxonomical botany in Nova Scotia" (Piers 1938: 22-23).

Please note that except in a few instances for clarification purposes, Smith's spelling, grammar, and sentence structure have been maintained.

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[1] I want to thank Dr. Robert Cameron for providing helpful information on changes in forest composition since the inventories carried out by Smith.

[2] Also, my sincere thanks to Grace McNutt for the transcriptions of Smith's original documents.

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## APPENDIX ONE

***Observations of the Nature and Uses of Trees***

**1. Larch, Hackmatac or Juniper**

This is the strongest and most durable timber among the trees of the Pine kind, which we have, but it does not grow to a large size being seldom more than a foot diameter. It is seldom used for any purposes except making fencing poles; for which it answers better than any other timber but the poles should not be too small, for the sap which is usually about an inch thick, decays very soon. It grew naturally in very barren places, either upon very poor, dry gravel, upon rocks or in cold mossy swamps.

**2. White Pine**

This tree is the tallest of any that grew in our records, although it does not come near the height of White Pine of New Hampshire and some other parts of the American states: here we consider it to be a large pine, which is 3 feet diameter and 60 feet high to the branches. I have seen a few trees which were 4 feet diameter. The timber is generally shakier (full of small cracks) than it is in the States: owing probably to the high winds which bend the trees backwards and forwards, and the situation of the trees, which most commonly grew by the sides of lakes, where they are much exposed to the Winds.

The use of the tree is well known, oars are chiefly made from it as are also shingles, building timber, masts, yards, etc. There is no timber we have so easily worked. It grows naturally in every kind of barren soil, whether wet or dry. It is to be found in all rocky barrens, but it is there so short and scrubbed as to be of no value. The best pine is to be found on a sandy soil, which is not very rocky or very near the sides of lakes.

**3. Yellow Pine**

This is frequently called Pitch Pine, but I do not think there is any real pitch pine in the Colony. This is a better tree for mast timber than the white pine of this country when large enough as it is usually straight which is seldom the case with white pine and it has no branches till near the top. A tree 2 feet diameter is generally 60 feet high to the branches. It grows in the same soil as white pine but is much more scarce.

**4. Hemlock**

This is one of our largest trees: it is commonly from 2 to 3 feet diameter, and 60 or 70 feet high. It has the figure of the White Pine as the trunk diminishes very little till it reaches the branches, which usually begin about 40 feet from the ground. This tree is remarkably shakey which prevents it from being much used for plank or boards, or even for building timber. It is used for Wharf logs and all our laths are made from it. The most valuable part of it is the bark which is very good for tanning leather. The wood is used for fuel by the bakers but crackles to much to burn in an open fire. It grows most commonly in gravelly soils, which are poor, but better than the soil of pines. It grows also, but more rarely upon a clayey soil, which is sometimes very good.

**5. Balsam Fir**

This is not a large tree being seldom more than 15 inches' diameter. It is very straight and tall and forms a very regular cone by means of its branches. The wood decays very soon if exposed to weather. It is much used for fencing small tubs and buckets as it is very light. It is also much used for fencing poles and pickets, as it is more frequently found of a proper size for these uses than any other kind of wood. The balsam is contained in their white membranaceus bladders which lie in the substance of the bark very near the outside. It abounds most in those trees which are thrifty and grow the fastest provided they are shaded. That balsam is best which is collected from the tops of very young trees, being much more valuable and pungent than that which is found upon old ones. It is a good remedy for pains in the breast, internal bruises, and the rheumatism which is the consequence of hard drinking.

The bark of very young trees is mucilaginous a decoction of this is often useful in the gravel and in most cases where directions are needed. It is of great use in long continued coughs, which threaten a consumption, and may be given in safety where the balsam itself cannot on account of fever. The balsam is applied to fresh wounds, but it frequently does harm causing inflammation. The Indians make a kind of Poultice of it by scraping and pealing the bark of very young trees into a mucilage, which is a very good application to fresh wounds: fir grows in almost every kind of soil, but thrives best in that which is moist and rich.

**6. White Spruce**

This is a large tree much resembling the red spruce: it is however a hard wood and a stronger timber. It is never used for making small beer as it has a disagreeable smell and taste. It grows on poor gravelly land and is not plenty in any place that I have seen.

**7. Red Spruce**

This is the tallest tree we have except the White Pine. It is commonly straight. The top takes the figure of a cone. It is much used for building timber, mast timber, and boards, and sometimes for shingles: it is stronger than white pine for many but the boards are much inferior to Pine for many purpose, as they decay much sooner if exposed to the weather, are very hard to plane, and very subject to warp and shrink.

It is more plenty than pine and consequently more used for mast and building timber. It grows in dry gravelly land in general which is neither very fertile nor very barren.

**8. Black Spruce**

This is probably a variety of the red spruce, occasioned by the difference of the soil. It grew in the most barren places, on rock, in wet mossy swamps, and on very barren land or gravel. The wood is harder than that of Red Spruce, owing to its slow growth for every kind of soft wood is harder in the part where the grains or years growth join and consequently the timber is firmest in those trees which grow the slowest as this hard part is of nearly the same thickness whether the grains is thicker or thin. The leaves are a trifle larger than those of Red Spruce and have a little difference in their taste. The use of this for making beer is well known, the Red Spruce is sometimes also used in beer but is said to give it a pungent quality. I imagine that this is owing to turpentine, which is much more commonly sticking to the branches of the Red than the black spruce. The black spruce when large enough the timber is much inferior to the red for the grain always twists very much, and it is almost always very knotty, the branches growing nearly the whole length of the tree.

The roots of both the red and the black spruce do not strike into the ground, but spread horizontally, covered only by the turf and moss which always overspreads such land as spruce grows on.

**9. Mountain Pine**

I have never seen this tree, except on the tops of high hills of Rock where it is very short and scrubbed, that I cannot judge what size it might grow to in suitable soil. It is very scarce; its leaves are not more than half the length of those of White Pine. The cones (Strobili) which contain the seed differ remarkably from those of other pines being nearly as hard as bone.

**10. Black or Yellow Birch**

This differs a little from the Black Birch of New York being a stronger kind of timber, and the bark of the young seedling trees being always yellow here whilst at New York it is black. This difference may be occasioned by the difference of climate as ours agrees with the black birch of Linnaeus. This is large tree frequently 3 feet diameter. The bark is sometimes used for tanning leather, but is not accounted equal for this purpose than that of Hemlock. It is much used for ship building both for timber and Plank and it is said to be less liable to damage from worms than Oak, on account of the better gum which it contains. It is also much used by Cabinet makers for household furniture. Bedsteads said to be made from the heart of birch are said to be free from bugs. The hoops used by the Coopers at Halifax are made from Yellow Birch as are all cartwheels. This tree is almost always to be found on good land and often on a very poor soil it enriches the land where it grows. If the soil be poor, it frequently sends of horizontal roots to the distance of over 60 feet.

**11. White Birch**

This tree always forms the principal part of such forests as grow up when the original growth of Timber has been destroyed by fire provided the soil is not extremely barren. The outer bark is an article of great consequence to the Indians: if it contains a kind of resin which renders it incorruptible in the Weather and impenetrable to Water. Their canoes are made by covering a slight frame of their laths with the bark. They choose for this purpose, that which is sound and near 1/8 of an inch thick. They then sew the different pieces together, with the roots of Spruce or Larch split in halves and cover the seams with Spruce resin. These canoes are lighter than could be made from any other materials and are easily carried from one lake to another. The Indians also frequently cover their camps with this bark and some few have tents made of it by sewing a number of pieces together which they carry with them in their canoes. They always have at their camps a clumsy vessel made of birch bark to fetch water in, with it also they very neatly make bowls to put their soup in, baskets and boxes ornamented with the quills of the Porcupine dyed of various colors – As it burns with a fierce flame they use it for flambeaus to spear Salmon, Lobster and other fish which they catch by night. The wood itself is the worst fuel we have, and it is not-much used for any other purpose except Charcoal for which it answers very well.

**12. Dwarf Birch**

This is only a small shrub. It grows on mosey bogs.

**13. Beech**

This forms the greater part of the Woods in our best land, what is called hardwood land being generally chiefly covered with beech, with a small proportion of birch and maple. It forms our principal fuel. Our new cleared land fences are commonly made from the logs but they soon decay: if they are split into rails, they will continue good for three times as long as whole logs. Sleds are commonly made of this wood, and it is sometimes used for barrel staves, but it is not as yet much worked for any other purpose. Hogs are fattened with the nuts in those seasons in which they are plenty: but as far as I have observed they are blasted about half the year.

**14. Sugar Rock Maple**

This tree when it has its full growth is from 2 to 3 feet diameter. It abounds principally in the Eastern part of the Colony. The land is always very good where this tree is frequent. It grows chiefly in moist grounds near small brooks and upon intervals. It is very frequent upon Limestone land.

The sap or Juices which yields the sugar will run from the tree if cut or wounded in any warm day after middle of December. It will run at that season very slowly and continues to increase in quantity till the middle of April which is about the time that it ceased to flow when the weather becomes so warm as to swell the buds of the trees and loosen the bark. The season for making sugar is commonly between the middle of March and the middle of April. The sap runs only in warm days which are preceded by a frosty night. If the weather should continue warm, the sap will seldom run for more than 24 hours it then stops, and does not run again till there comes another frosty night. The sap is best in the beginning of the season: it then yields the most and the best sugar. The very last sap is commonly fit only to make molasses. At the beginning of the season 4 gallons' wine measure will yield a pound sugar: at the close it will require 5 or 6 of the same quantity. Such trees as are left in cleared land will yield more sugar from the same quantity of sap, but they do not produce as much sap as those which stand in the woods. There is no kind of work which requires more constant attention than making Maple sugar, as the running of the sap depends so much on the changes of the weather. For this reason, the greater part of those who attempt to make it do not manufacture the third part which they might with a little care and attention. The trees ought to be tapped with a chisel or an augur as they will them continue good for a long time but when tapped with an axe as is common by the ease they are much sooner exhausted. It is a good season in which the trees yield 600 pounds of sugar each on an average.

The wood of the tree is very hard and solid, it is superior for fuel to Beech or Birch: it is very frequently curled, the grain running in the small waves, and sometimes but more rarely becomes what is called Birds eyed by having the substance of the wood full of very small knots. The curled or birds eyed Maple makes very handsome furniture. Hard maple is frequently used for felloes for cart wheels, but it decays very soon when exposed to the weather.

**15. Flowering of White Maple**

This tree grows upon almost every kind of soil; it thrives most near the water. It is covered with red flowers very early in the Spring before the leaves appear and the leaves generally change to red on the approach of Autumn. It is harder than the soft Maple at New York; but it is much inferior to it for timber, as the grain twists very much. It is sometimes used by Chairmakers to turn: but they commonly prefer Yellow birch. It makes good fuel when dry, but very indifferent when green.

**16. Moose-wood Maple**

This is a small tree, very rarely more than 4 inches' diameter; it is not used for any other purpose that I know of except for fencing stakes: it is of very quick growth and the wood is very soft and brittle. Its twigs are the principal Winter food of the moose where they can find it (for it does not often grow on very barren land). It is in most plenty near small brooks, in stony Hemlock land.

**17. Dwarf Maple**

This is not above half the size of the last mentioned species. It is very troublesome bush upon new cleared land, as it grows very fast, is not easily destroyed.

**18. Elm**

This tree is very rare except on the Intervals in the Eastern part of the Colony: there it grows to a large size, often 3 or 4 feet diameter it is a firm solid kind of wood, the bark is very tough and strong and is used to make ropes and chair buttons. The ashes of any given quantity of Elm will often yield more potash than the ashes of four times as much beech or birch.

**19. Horn-beam**

This tree grows only upon good land especially intervals, it is seldom of a large size, it is the hardest and strongest wood we have: it is much heavier than water and will sink in a swift stream. It is the best timber for Axe helves, rake teeth, etc.

**20. Black Pigeon Cherry**

This tree is very rare except upon intervals. It is not so large in this Colony as in the United States further southward where it is after used to make tables, as it has nearly the color of Mahogany. In Nova Scotia it is seldom more than 16 inches' diameter. The fruit is small growing in long bunches, it is when fully ripe pretty good to eat and is accounted very good to put into Spirits.

**21. Red Cherry**

This tree is seldom more than 16 inches big. It commonly springs up on dry stony land, after a fire. The fruit is small and very sour.

**22. Choak Cherry**

This is only a bush, being seldom more than big [diameter]. It is common upon interval by the sides of brooks on rich moist upland. It has long branches of fruit rather longer than that of either of the other two species, but is scarcely eatable, having a disagreeable astringent taste.

**23. White Cedar**

This tree grows in no place that I know of except in the Valley of Annapolis River, and there it is not plenty. It is not the same tree which is called White Cedar in the Southern States, although there is no great difference in the timber. It is excellent for Shingles, tubs and buckets, being very durable and not so apt to imbibe water as white pine. The same quality makes it good for building ships or boats, but it is so scarce in this Colony as to be no consequence.

**24. Trembling and White Poplar**

These trees differ but little from each other: they always grow upon land that had been burnt over along with the White birch. They are tall but seldom more than 16 inches' diameter. The Wood is soft and light and is used to make trays, it is sometimes sawed into boards, it is springy and very bad to saw, it makes but poor fuel for common use, yet it is very good for Charcoal.

**25. Mountain Ash or Fowlers Service**

This is a small tree, very rarely 6 inches' diameter, it grows most frequently on very poor land, the bark of this has very nearly the same taste as that of the cherry tree. It is the favourite food of the beaver and I believe it is the natural breeding place of the insects which destroy some many apple trees near Halifax by covering the branches with small nests which resemble lice, having frequently observed the bark of this tree covered by them, in places which were 20 miles from any settlement.

**26. Wild Indian Pear**

This is a species of Medlar (Mespilius). It seldom exceeds 6 inches' diameter. It grows most commonly on barren land, near to water, it is a remarkable flowering tree, and bears very good fruit about the size of cherries, it is however very frequently blasted, the wood is very hard and smooth and is sometimes used for axe helves.

**27. Oak**

We have but one species of this tree, that I have seen: it resembles the Red Oak in the States, but is harder and stronger. It grows chiefly on poor land, the best I have seen was upon very sandy intervals. It is more durable when exposed to the Weather than any other kind of hardwood we have. It is used for Plank and Timber for ships, for staves for fish barrels, cartwheels and many other purposes. It is scattered over every part of the colony, but that which is of a size as to be valuable is mostly in the Eastern District.

**28. White Ash**

This is a very tall tree and very strong (except when it grows in cold swamps where it is soft and brittle). It usually grows on rich land and by the sides of brooks. It is the most suitable timber to make handles for tools, ploughs, carriage wheels, and for many other purposes. When green it is better fuel than any other wood we have.

**29. Black Ash**

This grows only in swamps which, though rich, are sometimes so wet as to require draining to produce grass. The Canada flour barrels are made from this tree, but I have never seen any "great" quantity of it, of a size fir for staves in this colony. It is here used to make baskets: to fit it for this purpose it is beaten with a maul which separates the grains or years growth. It makes very bad fuel when green.

## APPENDIX TWO

***List of Trees***

The Common and Scientific names provided by Smith are shown in columns one and two. The numbers in brackets after the common names note the trees discussed by Smith in his *Observations of the Nature and Uses of Trees*. Number 24 is repeated twice because two species (trembling and white poplar) are discussed under that entry. The list also includes other species not discussed, possibly because Smith lacked substantial information about their nature and uses. The modern scientific nomenclature for each tree is given in the third column based on the Nova Scotia Natural Resources (2007) *Tree Identification Guide for Common Native Trees of Nova Scotia*, and Clark and Gorham's scientific designations (Clark 1954:308-309, Gorham 1955:122-123).

| Smith's Common Names | Smith's Scientific Names | Modern Scientific Names |
|---|---|---|
| Larch, Hackmatac, or Juniper (1) | *Pinus Larix.* | *Larix laricina* (Du Roi) K. Koch. |
| White Pine (2) | *Pinus Strobus.* | *Pinus strobus* L. |
| Yellow Pine (3) | *Pinus Silvestria.* | *Pinus resinosa* Ait. |
| Hemlock (4) | *Pinus.* | *Tsuga canadensis* (L.) Carr. |
| Balsam Fir (5) | *Pinus Balsamifera.* | *Abies balsamea* (L.) Mill. |
| White Spruce (6) | *Pinus.* | *Picea glauca* (Moench) Voss. |
| Red Spruce (7) | *Pinus.* | *Picea rubens* Sarg. |
| Black Spruce (8) | *Pinus.* | *Picea mariana* (Mill.) BSP |

*Table cont'd*

| **Smith's Common Names** | **Smith's Scientific Names** | **Modern Scientific Names** |
|---|---|---|
| Mountain Pine (9) | *Pinus Pinea.* | *Pinus banksiana* Lamb. |
| Black or Yellow Birch (10) | *Bitula Nigra.* | *Betula alleghaniensis* Britt. |
| White Birch (11) | *Bitula Alba.* | *Betula papyrifera* Britt. |
| Dwarf Birch (12) | *Bitula Nana.* | *Betula populifolia* Marsh. |
| Beech (13) | *Fagus Silvatica.* | *Fagus grandifolia* Ehrh. |
| Sugar Rock, curled, or Birdseye Maple (14) | *Acer saccharinum.* | *Acer saccharum* Marsh. |
| Red Flowering or White Maple (15) | *Acer Rubrum.* | *Acer rubrum* L. |
| Moose-wood Maple (16) | *Acer.* | *Acer pensylvanicum* L. |
| Dwarf Maple (17) | *Acer Mana.* | *Acer spicatum* Lam. |
| Elm (18) | *Ulmus Americana.* | *Ulmus americana* L. |
| Hornbeam (19) | *Carpinus Ostria.* | *Ostrya virginiana* (Mill) K. Koch. |
| Black or Pigeon Cherry (20) | *Prunus.* | *Prunus serotina* Ehrh. |
| Red Cherry (21) | *Prunus Avisim.* | *Prunus pensylvanica* L. f. |
| Choak Cherry (22) | *Prunus Virginica.* | *Prunus virginiana* L. |
| White Cedar (23) | *Thaja occidentala.* | *Thuja occidentalis* L. |
| Trembling Poplar (24) | *Populus tremula.* | *Populus tremuloides* Michx. |
| White Poplar (24) | *Populus Alba.* | *Populus grandidentata* Michx. |
| Mountain Ash or Fowlers Service (25) | *Sorbus Aucuparia.* | *Sorbus americana* Marsh. |
| Wild or Indian Pear (26) | *Mespilus.* | *Amelanchier canadensis* Medic. |
| Oak (27) | *Quercus rubea.* | *Quercus rubra* L. Michx.f. |
| White Ash (28) | *Fraxinus Americana.* | *Fraxinus americana* L. |
| Black Ash (29) | *Fraxinus.* | *Fraxinus nigra* L. |
| Shrub Maple | *Acer.* | *Acer ginnala* Maxim |
| Alder | *Alnus.* | *Alnus alnobetula*(Ehrh.) K. Koch |
| Balsam Poplar | *Populus Balsamifera.* | *Populus balsamifera* L. |
| Button Wood or Sycamore | *Platanus Occidentalis.* | *Platanus Occidentalis* L. |
| Lyme Tree | *Tilia.* | *Tilia americana* L. |
| Thorn | *Crataegus Crus Galli.* | *Crataegus crus-galli* L. |

## APPENDIX THREE

***Letter from Wentworth to Smith***

Wentworth's complete unedited letter to Smith (Wentworth 1801) is enlightening because beyond searching for timber and other resources to fulfill the Admiralty's needs, his instructions to Smith indicate just how little the government knew about the geography and natural history of the interior of the colony. After all, at the same time Smith was trekking through mainland Nova Scotia, Alexander von Humboldt [1769-1859] and Aimé Bonpland [1773-1858] were in the third year of their five-year expedition exploring South America [1799-1804], and in 1804, Thomas Jefferson [1743-1826] was preparing to send Captain Meriwether Lewis [1774-1809] and Lieutenant William Clark [1770-1838] westward through the continental divide to the Pacific coast to expand and redefine the new nations geographical and political identity.

Unfortunately, the identity of Mr. Carter remains unknown. Wentworth mentions him as Smith's paid companion (11 shilling eight pence for Smith, eight shilling for Carter), but never gives a first name, or military rank.

> "To Mr. Titus Smith, Jr.,
>
> Sir: Government having expressed a desire that means should be adopted in this province, to encourage the growth of Hemp; at the recommendation of a committee appointed for this purpose, I have thought it proper to accept your offer, jointly with Mr. Carter, to make a survey of so much of the peninsula of Nova Scotia as can be accomplished within the periods herein limited, and you will take the following instructions as your guide.
>
> 1st. You will consider your engagement to expire at the end of fifty days, reckoning from the day from which you set off, unless renewed by our express order, in writing from myself or the secretary of the province; for which service you shall receive eleven shillings and eight pence, Halifax currency, each day for yourself, and eight shillings each day for Mr. Carter, during your actual services, in full for your pay and every contingency. You will contrive to be so situated on or a little before the fiftieth day, as to hear from me or the secretary of the province.

2nd. Your principal object in this survey will be, to visit the most unfrequented parts, particularly the banks and borders of the different rivers, lakes, and swamps, and the richest uplands, for the purpose of discovering such spots as are best calculated for producing hemp and furnishing other naval stores. You will make your remarks on the soil, the situation of the lands, and the species, quality and size of timber; the quantity of each sort also, and the facility with which it can be removed to market. The thickness and length of mast timber you will attend to in an especial manner; and in every place, which you shall deem calculated for these purposes, you will, as near as possible, estimate the quantity of acres, the possibility and means of rendering them fit for cultivation, either by banks, drains or otherwise.

3rd. You will receive from the Surveyor-General such a map of the Province as our present knowledge of the country can furnish; you will endeavour, as far as lies in your power, to correct any errors in it, and on your return you will deliver to me the same with another containing these corrections and the route which you shall have gone distinctly placed on it.

4th. You will in the first instance, go to the eastward of the harbour to the spot from whence issue the heads of the Rivers Stewiacke, Musquodoboit, and Saint Mary, and wherever else, in consequence of the information you may receive, you may be led to suppose the objects of your inquiries are to be found. Having examined the eastern side of the province, from the Shubenacadie, the Dartmouth Lakes, and the harbour of Halifax, you will proceed to the western side and examine the lands about the River Saint Croix, and the land of St. Margaret's Bay and thence along the northern side of Chester, Lunenburg, Liverpool, Shelburne, and Argyle, as far as Yarmouth, and the heads of those waters which empty themselves into the Atlantic. You will endeavour to examine Lake Rossignol, and will consider it to be a very principle object of your tour. You will trace those rivers, as far as anything desirable is to be obtained from such an investigation, towards their mouths, which empty themselves into the River Annapolis or the Basin at Minas; and if within your power, without losing much time, you will examine the mountains which run parallel to the Bay of Fundy, to the southward of the Annapolis River. The last object of your searches will be the inland country situated between Bramshag and Bay Verte in the N.E. and the Basin of Minas in the S.W.

5th. What is expressed in the second and fourth articles of these instructions, you will consider as your principle objects; but if in the course of your travels you should meet with any objects in natural history, or find any inducements of importance, the investigation of which is evidently for the benefit of the public, you will use your discretion, provided they do not occasion any essential delay or in any respect draw you away from the main objects of your research, which must not on any account be sacrificed or even impeded.

6th. You will not omit to give me every information in your power by the fourth day of June next, after which you will forward your intelligence by every favourable opportunity. In order to facilitate the present design, I have given directions to the secretary of the Province to deliver you a circular letter, directed to all magistrates and other persons throughout the province, to afford you all the assistance in their power; but you will take care not to require anything from them which shall occasion an additional expense from the government.

7th. Your communications will be in the form of a journal, with reference to notes at the end, which will contain the detail. You will always make use of names used by the present inhabitants, and refer to a table of Indian and French names and terms, with a view of correcting the arbitrary names of late years introduced in the maps of the province.

J. Wentworth.
Halifax, Nova Scotia, May 2nd, 1801”.

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# POPULATION CHARACTERISTICS AND MOVEMENTS OF STRIPED BASS *MORONE SAXATILIS* (WALBAUM, 1792) IN THE MIRA RIVER ESTUARY, CAPE BRETON ISLAND, NOVA SCOTIA, CANADA

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## ABSTRACT

The occurrence of striped bass outside the immediate vicinity of known spawning rivers in Canada is neither widely understood nor well studied. Striped bass in Canada are managed and assessed within three distinct units, the Bay of Fundy, the Gulf of St. Lawrence, and the St. Lawrence River; but stocks that may occur outside these units are unrecognized. We document a previously unstudied aggregation of striped bass in the Mira River estuary (MRe), Cape Breton Island (46° 01′N, 60° 03′W), a location on the east coast of Nova Scotia omitted from present management units but which has been long reported to host an aggregation. From July 2012 to November 2014, 62 striped bass within MRe were sampled and 31 were surgically implanted with VEMCO acoustic transmitters. Striped bass ranged in size from 31.6 to 125.0 cm total length and age 3 to 24 years. Acoustic telemetry from 2012 to 2015 elucidated residency and fidelity to the MRe with mid-estuary overwintering every year, freshwater residency of the adult population during spring, and a summer through autumn aggregation in the lower estuary. Of the 31 acoustically tagged striped bass, 24 remained in MRe throughout the study, six exhibited mid-summer departures to the Atlantic Ocean but returned by mid-autumn, while one left the MRe and was never detected again. Mira River SB with acoustic tags were never detected at nearby Ocean Tracking Network telemetry infrastructure. Striped bass stocks exhibit similar residency and fidelity patterns to their natal rivers and estuaries elsewhere in its Atlantic coast range which

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suggests the Mira River aggregation constitutes a possible distinct stock yet unrecognized by Canadian fisheries managers.

Keywords: acoustic telemetry, fidelity, wintering habitat, residency, zoogeography

## INTRODUCTION

Anadromous fishes exhibit complex migratory strategies ranging from multi-year marine migrations to lacustrine residency (Borman & Lewis 1987, Hansen & Jonsson 1991, Dadswell *et al.* 2010), with intra-specific variation in timing and routes, and distinct intrapopulation contingents using multiple migration strategies (Clark 1968, Dadswell *et al.* 1987, Chapman *et al*. 2012, Gahagan *et al.* 2015). Contingents are differentially susceptible to anthropogenic perturbation, such as development, pollution, and exploitation, depending on the nature and scale of their migrations and are therefore important to identify (Buhariwalla *et al.* 2016, Keyser *et al.* 2016, Dadswell *et al.* 2018). Advances in acoustic telemetry and proliferation of telemetry research networks (O'Dor & Stokesbury 2009, Cooke *et al.* 2011, Hussey *et al.* 2015, Bangley *et al.* 2020) enables spatiotemporal resolution of movements ranging from fine scale foraging behaviour (McLean *et al.* 2014) to identification of previously unknown migratory patterns and contingents of fishes (Secor 1999, Keyser *et al.* 2016), and also provides data on critical habitat of importance for species of conservation interest (Dadswell & Rulifson 1994, Kessel *et al.* 2016, Crossin *et al*. 2016, Andrews *et al.* 2018).

Stiped bass *Morone saxatilis* (Walbaum, 1792) is a long-lived, economically, and ecologically important anadromous species native to watersheds and coastal regions of eastern North America from the Gulf of Mexico to Labrador (Merriman 1941, Scott & Scott 1988, Rulifson & Dadswell 1994, Robitaille *et al*. 2011, Andrews *et al.* 2019a). Throughout its range, striped bass support high value commercial and sport fisheries and has been subjected to various conservation measures including total allowable catches (TAC), commercial closures and risk assessment (Field 1997, Richards & Rago 1999, COSEWIC 2012, Broome 2014, ASMFC 2016). In Canada, however, commercial fisheries were closed by 1996 and the species is now managed to support recreational angling and First Nations' fisheries (Douglas *et al.* 2003, Bradford *et al*. 2012). Successful management of this euryhaline species depends on identification of the migratory strategies within the stock of interest (Able *et al.* 2012, Andrews *et al.* 2017).

Striped bass migratory strategies are highly variable. Stocks at the southern extreme of their range exhibit riverine and estuarine residency, potentially avoiding marine thermal barriers to coastal migration and survival (Hess *et al.* 1999, Bjorgo *et al.* 2000, Nelson *et al.* 2010). Stocks between North Carolina and New Brunswick exhibit long distant marine migrations (Setzler-Hamilton *et al.* 1980, Waldman *et al.* 1990, Rulifson *et al.* 2008, Mather *et al*. 2010, Douglas & Chaput 2011, Andrews *et al*. 2019a), however, otolith microchemistry analyses indicate the presence of riverine and estuarine resident contingents within some stocks (Secor & Piccoli 1996). These strategies are somewhat variable with marine migration demonstrated to increase with age. Further complicating the contingent concept, migratory striped bass take up residence in non-natal estuaries to which they often exhibit annual fidelity (Grothues *et al.* 2009, Mather *et al.* 2009, Pautzke *et al.* 2010, Gahagan *et al.* 2015, Andrews *et al.* 2018). These behaviors are well documented in American and Canadian stocks, however, in Canada information is limited and based on conventional tagging, fisheries observations, and telemetry projects focused near known spawning rivers (Douglas *et al*. 2009, Broome 2014, Keyser *et al.* 2016, Dunston *et al.* 2018, Andrews *et al.* 2019b).

Striped bass are known to occur along the eastern coast of Nova Scotia, north to Cape Breton Island coastal waters (Fig 1; Bigelow & Schroeder 1953, Scott & Scott 1988), and its inland sea, Bras d'Or Lake (Cash *et al*. 1985). Cape Breton straddles two management zones (Designatable Units - DUs) in which striped bass were assessed as threatened and/or endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2012) but are unlisted in this region by the Canadian Species at Risk Act (SARA). Little published data exist on striped bass biology, populations, or movements within Cape Breton (Leblanc *et al.* 2020). There have been, however, significant angling catches in the region that have produced all-time Canadian angling records and Nova Scotia yearly angling records including 26.8 and 24.5 kg striped bass from Bras d'Or Lake and the Mira River estuary (MRe), respectively (NSDFA 2007, NSDFA 2018, Andrews *et al.* 2019a).

In this study we focused on the Mira River estuary in eastern Cape Breton (Fig 2). Striped bass were captured by angling for demographic assessment and acoustically tagged to evaluate their residency, movements, and potential migratory strategies. The objectives of this study were to: 1) examine population characteristics; 2) identify residency patterns and seasonal movements within the estuary; 3) identify critical estuarine habitat; and 4) detail interactions with the Ocean Tracking Network (OTN) telemetry infrastructure in the region (Fig 1). The biology of striped bass in the MRe was unknown before this study and conventional thought suggested these fish were a migratory contingent occupying the estuary for summer foraging (Leblanc *et al.* 2020).

We suggest that if the aggregation was a migratory contingent then striped bass would exhibit autumn migrations to wintering habitat near their natal systems OR exhibit spring migrations to spawn in natal systems. If striped bass exhibited annual residency within MRe,

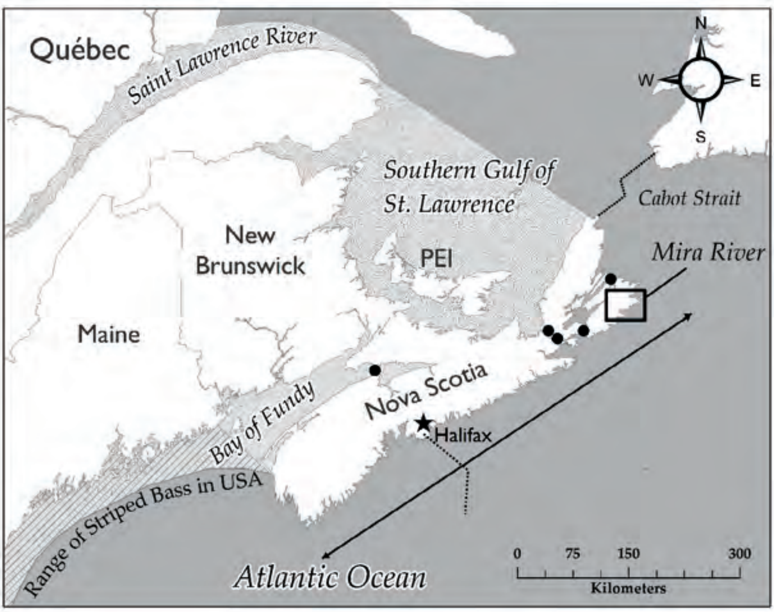


**Fig 1** **The location of the Mira River estuary and Ocean Tracking Network acoustic telemetry infrastructures deployed in Atlantic Canada during 2012-2015. Dotted lines indicate large-scale marine, telemetry arrays. Larger black dots indicate the location of smaller arrays that were deployed during the study period. The double pointed arrow along the Nova Scotia coast indicates the break in known Canadian striped bass stocks. Shaded regions are the Department of Fisheries and Oceans and COSEWIC designated zones for striped bass management. Crosshatching indicates the range of striped bass stocks in the United States.**

especially during the spring spawning period, then these fish possibly constitute a previously undescribed spawning stock.

We postulate that striped bass adopt a life history strategy at the southern and northern ends of their Atlantic coast range that permits survival of stocks by utilizing freshwater refugia to avoid unfavorable marine environments. The results of this study may fundamentally change our understanding of the striped bass at the northern extreme of their range and should inform future research and management decisions.

## STUDY SITE DESCRIPTION

The Mira River estuary located in eastern Cape Breton Island, Nova Scotia (Fig 1; 46° 01′N 60° 03′W) flows approximately 45 km from headwaters at MacMulins Lake to confluence with Mira Bay on the Atlantic coast (Fig 2). The drainage area of 645 $km^2$ encompasses many small brooks, with the only major tributary, Salmon River, located 11.5 km from the head of the system. The MRe was historically a chain of kettle lakes connected by small river channels (NSDOE 1976), however, recent submergence of the Atlantic Coast of Nova Scotia caused by post-glacial isostatic adjustment (1.2 m over the last 1000 years; Grant 1970, Bousfield & Thomas 1975) has resulted in flooding of the river valley to form large shallow bays (2-4 m deep) connected to the former lake sections (15-27 m deep) and tidal influence that extends to the head of the system.

Despite its name, the Mira River is essentially a large estuary. Surface waters throughout the estuary are dominated by freshwater discharge during periods of high precipitation in the spring and autumn, but during the summer a salt wedge penetrates the upper reaches of the estuary with salinity detected at the head of the system (0.1-0.2). Pycnoclines typically occurred all year in deep sections throughout the system at depths of ~3-6 m, while shallow sections maintain similar characteristics as the upper strata of nearby deep holes. Intermediate depths within the mid-estuary maintain greater temperatures in the late fall than surface or bottom waters. Anoxic conditions do occur in some of the deep holes when strong thermoclines and/or pycnoclines are present.

A HOBO U20-001-04 (Onset Computer Corporation, Cape Cod, Massachusetts) water level logger was used to measure tides in the mid estuary from July through November 2013. The logger was programmed to log water level (±0.3 cm) every 15 minutes and moored immediately upstream of Albert Bridge (Fig 2). HOBOware Pro was used to setup, download, and apply barometric pressure correction (obtained from Environment Canada's Sydney weather station) to observed water levels, while the 'R' package 'TideHarmonics' (Stephenson 2016) was used for analysis. A HOBO Pendant temperature logger was also deployed immediately upstream of Albert Bridge and recorded hourly temperature readings from July 2012 through May 2015.

Temperature, salinity (PSU), and dissolved oxygen (DO) were measured at stations throughout the MRE from May to November 2013 (Fig 2). Sampling was from a 5.5 m vessel and a GPS (Garmin Etrex HTC; accuracy ± 3 m) was used to navigate to stations. Bow and stern anchors were used to minimize boat drift and swing due to currents and wind. The water column was sampled using a YSI-63 for temperature/salinity and a YSI-550a for dissolved oxygen (YSI Inc., Yellow Springs, Ohio). Sampling was conducted at 0.5 m increments around pycnoclines, 1 m increments when gradients existed, and 2 m increments when the water column was homogenous for temperature and salinity–a change of less than 1.0°C or 1.0 PSU per meter depth.

**Zones**

Zones were chosen *a posteriori* based on movements and residency patterns of striped bass and to reflect natural divisions within the estuary. Zone 1 began at Mira Gut (Fig 2), the confluence of the MRe with Mira Bay and the Atlantic Ocean, and contained a channel 5-11 m deep, 70-100 m wide, and 3 km long that leads from the sea to a section of the lower estuary 1-5 m deep, 500-700 m wide, and 2.5 km long. Tidal currents in Zone 1 prevented sampling from the mouth of the system, however, sampling did occur at the head of the zone. Temperatures in Zone 1 during the open water season ranged from 9.1-23.3°C and 16.2-19.5°C at the surface and bottom, respectively, except for November when it increased from the surface to the bottom. Salinity during the open water season ranged from 8.2-19.9 and 24.2-28.0 at the surface and bottom, respectively, with increasing salinity through the summer and decreasing in autumn. Dissolved oxygen through the sampling period ranged from 6.3-9.7 mg/L.

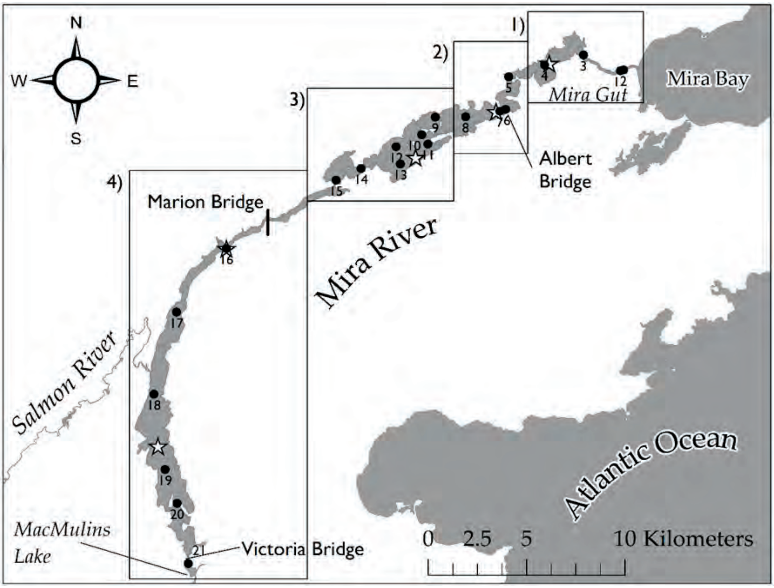


**Fig 2** **The Mira River estuary flows 45 km northeast from its headwaters in MacMulins Lake to its confluence with the Atlantic Ocean at Mira Bay. The largest tributary, Salmon River empties into the Mira from the west, 11.5 km from the head of the system. The four study regions of the Mira River estuary delineated by boxes include 1) Mira Gut 2) Lower Estuary, 3) Middle Estuary, and 4) Lake. Acoustic receiver stations deployed along Mira River to detect tagged striped bass are indicated by numbered black dots (1-21) and temperature, salinity and oxygen monitoring stations within regions are marked by stars.**

Zone 2 was a 5 km long stretch of estuary ranging from 90 m to 1 km wide, and consisted of shallow coves, deep open bays, and a meandering channel 5-20 m deep. Albert Bridge crosses at the narrowest point of the zone and spans a channel 100 m long, 90 m wide with an average depth of 4-9 m. The channel straddles two holes, 16 and 20 m on the down and up estuary sides of the bridge, respectively, and was the main summer-autumn aggregation site for striped bass. The water level logger deployed on the inner estuary side of Albert Bridge observed mixed semidiurnal tides with mean tidal range of 19.1 cm.

Temperature during the open water season ranged from 9.1-24.1°C and 3.3-21.5°C at the surface and bottom, respectively (Fig 3). A thermocline occurred between 3-4 m depth in July, while during May and June temperature decreased more gradually with depth. Water temperature

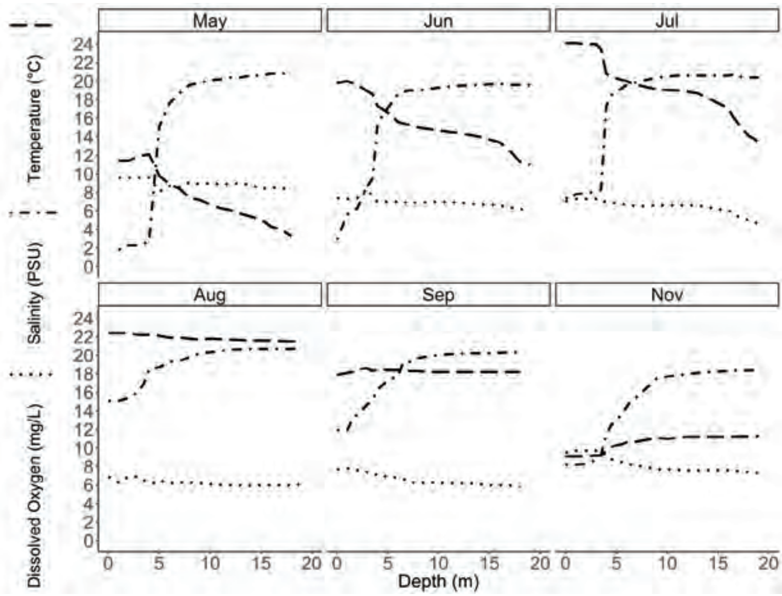


**Fig 3** **Temperature ( - - - - ), salinity ( - . - . – . - ), and dissolved oxygen (.....) profiles in Zone 2 from May through November 2013, in the striped bass aggregation site at Albert Bridge on the Mira River estuary.**

was relatively homogeneous throughout the water column during August and September. The lack of thermal stratification is likely a result of tidal mixing given the sampling site was located immediately upstream of the narrows at Albert Bridge. Salinity during the open water season ranged from 2.9 to 15.1 on the surface and 18.4-20.9 on the bottom. A halocline was present at 3-4 m depth until August when salinity increased on a gradient versus a sharply defined halocline; the gradient was maintained until November. Dissolved oxygen ranged between 6.9-9.5 mg/L and 5.0-8.2 mg/L at the surface and bottom, respectively.

Zone 3 was approximately 7 km long with widths ranging from 70 m to 2.5 km (Fig 2). Channel depth ranged from 4-10 m with several shallow bays (2-4 m) on the north side of the estuary and a large (2 km long) deep (11-23 m) section on the south side of the lower portion of the zone identified as the critical striped bass wintering site.

Temperature during the open water season in Zone 3 ranged from 9.0-23.3°C and 4.8-8.1°C at the surface and bottom, respectively. Temperatures above and below the thermocline were homogenous through depth strata until August when surface temperatures cooled

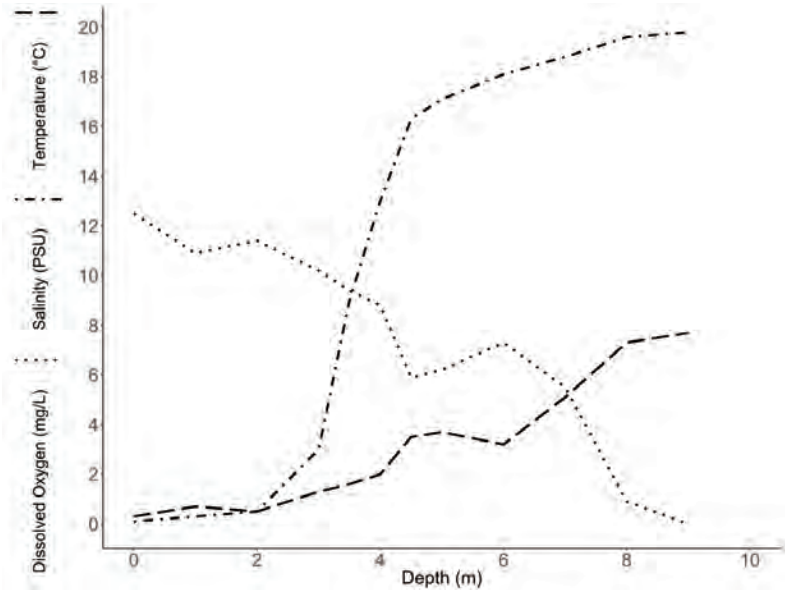


**Fig 4** **Temperature ( - - - - ), salinity ( - . - . - . - ), and dissolved oxygen (……) profile from February 18, 2014, at the striped bass overwintering aggregation site in Zone 3 of the Mira River estuary.**

and the temperature difference between surface and bottom began to increase. Strata between 1-3 m cooled more rapidly in autumn than those deeper causing a warm-water layer between 4-8 m. Salinity during the open water season ranged from 1.7-13.9 at the surface and 19.4-20.4 at the bottom. The halocline occurred between 2.5-6 m and salinity variation was steepest in the spring becoming more gradual by autumn. Dissolved oxygen was 6.9-9.8 mg/L at surface and 0.0-3.8 mg/L at the bottom. Surface DO was relatively high throughout the sampling period; however, anoxic conditions were encountered on the bottom during July and DO was typically ≤ 4 mg/L below 10 m across all months.

Because of hazardous ice conditions during all years of the study only one profile of the striped bass wintering site was completed in February of 2014. Temperatures ranged from 0.3°C at the surface to 7.7°C near the bottom (9 m) with a distinct thermocline present at 6 m (Fig 4). Salinity ranged from 0.1 at the surface to 19.8 at the bottom with a halocline occurring between 3-4 m deep. Dissolved oxygen ranged from 12.5 mg/L at the surface to 0.0 mg/L at the bottom with a steep decline from 7 m to the bottom.

Zone 4 was 18 km long and ranged from 110 m to 1.8 km wide with a channel depth of from 3-27 m. The down estuary portion of the zone consisted of a meandering channel (3-8 m deep) that opened into a large lake section (6-27 m depth).

At the seaward end of Zone 4 during the open water season surface temperatures ranged from 9.5°C to 23.8°C while bottom temperature was 9.3°C to 23.3°C. This site was located above a constriction in the estuary and the water column was well mixed. No thermocline was observed from May through November. Salinity was 0.1 throughout the water column until salt wedge ingress in July and August when salinity ranged from 2.9-4.8 and 4.5-7.8 at the surface and bottom, respectively. Dissolved oxygen was relatively homogeneous throughout the water column during the monitoring period and ranged from 6.3 to 10.2 mg/L.

In the lake section of Zone 4 during the open water season, surface temperatures ranged from 10.3°C to 22.8°C while bottom temperatures ranged from 10.2°C to 18.7°C (Fig 5). A thermal gradient was present from June through August, however, from September onwards, water temperature was homogenous throughout

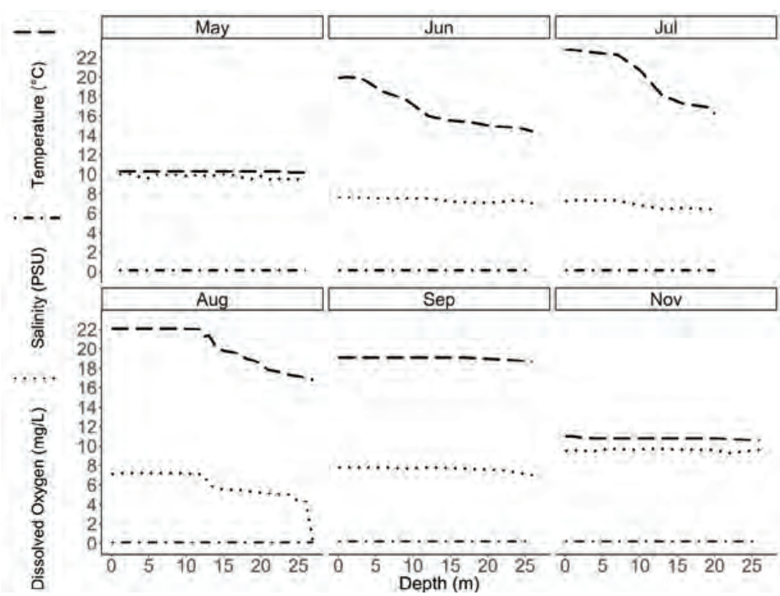


**Fig 5** **Temperature ( - - - - ), salinity (- . - . - . - ), and dissolved oxygen (…..) profiles from May through November 2013 in the Lake section of Zone 4 in the Mira River estuary.**

the water column. Salinity was 0.1 throughout the entire water column until September when it increased to 0.2 through to the end of sampling in November. Dissolved oxygen was typically homogeneous throughout the water column, ranging from 6.4 to 12.7 mg/L except during July when DO declined below 12.0 m and reached 0.0 mg/L near at the bottom (27 m), coinciding with the formation of the thermal gradient (Fig 5).

**Fish Capture and Tagging**

All striped bass except one were captured in Zone 2 at Albert Bridge (Fig 2) using rod and reel angling with 23 kg test braided line and 8/0-10/0 barbless circle hooks baited with available forage fishes or artificial fishing lures. Captured striped bass were immediately placed in an anaesthetic bath consisting of estuary water and 40 mg/L of a 10% Eugenol solution (clove oil, Hilltech, Vanleek Hill, ON: Lemm 1993). After 3-5 minutes, when opercular movements slowed, equilibrium was lost, and fish no longer responded to physical stimuli (running hand over the lateral line), they were sampled. Fork (FL) and total (TL) lengths were measured to the nearest 1 mm and weight (W) was obtained to the nearest 0.05 kg using a spring scale. Scales for aging were collected from above the lateral line between the two dorsal fins using forceps. A unique identifying dart tag (Floy® FT-1-94) with the address of Acadia University, Biology Department was inserted between the anterior pterygiophores under the first dorsal fin.

All striped bass considered large enough for acoustic tagging (body weight > 2% of tag weight) were then placed ventral side up in a padded V-shaped cradle on an incline, to ensure gills remained underwater, and intermittently irrigated with estuary water. Three rows of scales off the ventral midline were cleared from a patch ~2.5 cm long anterior to the anus. An incision ~2 cm long was made where a VEMCO® V13 transmitter (Bedford, Nova Scotia) was inserted into the body cavity, and the incision site closed with monofilament sutures (Ethicon® FS 5-0) tied with two horizontal mattress knots. All surgical tools were cold sterilized in 2% Gluteraldehyde (BM-28 PLUS; B. M. Group, Montreal, Quebec), while the transmitter and incision site (before and after surgery) were treated with 2% Chlorohexidine antiseptic (Stanhexidine Solution; Omega, Montreal, QC). Tools and transmitters were rinsed with sterile saline solution prior to use. Post-surgery, fish were recovered in gently flowing estuary water and released at the site of capture approximately 30 minutes after initial capture. All striped bass released with a transmitter were detected by receivers up and down estuary several days post tagging and all examined fish were considered to have survived handling and/or surgery. Tagging and surgery procedures were conducted under the Acadia University Animal Care protocol # 04-12 and a Department of Fisheries and Oceans Canada (DFO) scientific collecting permit # 337044.

**Acoustic Telemetry**

VEMCO® VR2w receivers were deployed and maintained from July 2012 to May 2015 at 21 stations in the Mira River estuary (Fig 2). Receivers were moored at 3-23 m depth in modified 17 x 40 cm PVC bullet floats with a 0.3-2 m nylon rope riser and anchored with ~20 kg nylon mesh bags filled with rocks. The initial array gated narrow (< 330 m) sections of the lower estuary to provide insight into behavior and inform future array design, since there was previously little knowledge of striped bass presence within the MRe. Due to limited number of receivers available to us, array configuration was modified across years to capture full extent of movements and to identify important habitat within the MRe. Sediment instability and transport in the lower section of the estuary and limited number of receivers resulted in no coverage within Mira Bay in the Atlantic Ocean outside of the estuary.

Range testing was carried out on all receivers. Because of the narrow nature of much of the estuary and lack of strong currents (except in Mira Gut) virtually every receiver could identify acoustic tags across the estuary except for those where the system was wider than 600 m (Fig 2).

The issue of false detections has been recognized to necessitate caution when dealing with acoustic detection datasets (Sipfendorfer *et al.* 2015). The White-Mihoff False Filtering Tool (White *et al.* 2014) was run in two stages. Stage one isolated individual tag numbers based on a subsequent detection interval of one second (s) to the minimum tag delay (50 s.); these detections could be created by detections on adjacent receivers or the collision of multiple tag transmissions. Stage two filtering used a detection interval of 60 minutes (*i.e.* solitary detections with ≥ 60-minute interval for preceding or following detection); these detections were then manually inspected and accepted or rejected based on behaviour of the 50 detections on either side of the suspect detection. If a single detection occurred at a station, the stations of previous and proceeding detections were compared to see if they occurred in a logical order (given the relative linearity of the system) and time. Detections identified as suspect were removed from the dataset.

**Sample Description and Data Analysis**

The geometric mean functional weight-length regression (equation 1; GMR, Ricker 1975) was performed using the log-transformed total length (TL mm) and weight (W kg) to calculate slope (*b*) and intercept (*a*) of the regression line where:

$$\log(\mathrm{W}) = \log(a) + b\cdot\log(\mathrm{TL}). \quad (1)$$

Due to unforeseen field events, only 57 of 62 sampled striped bass had associated weight measurements and were used in this analysis.

Striped bass scales were dried, cleaned in 70% ethanol, then mounted between two microscope slides for age analysis under a dissecting microscope (40X magnification, DeVries & Frie 1996). Three scales per fish were read by CFB and MJD. When disagreements occurred, we examined the specimen scales together and reached a consensus incorporating time of capture and length of the fish (Borgerson *et al.* 2014).

The Von Bertalanffy relationship was calculated using a plot of TL for age $t + 1$ against age $t$ to calculate TL∞ and K, and $\mathrm{Log_e}(\mathrm{TL}\infty - \mathrm{TL}_t)$ against age $t$ to obtain to (Ricker 1975) where:

$$\mathrm{TL}_t = \mathrm{TL}\infty(1-e^{-\mathrm{K}(t - to)}). \quad (2)$$

The K is the Brody coefficient and to the hypothetical age at which the fish was zero TL.

Three of the 62 striped bass sampled had scales that were unreadable and were removed from the data set.

A Residency Index ($\mathrm{I_R}$) was used to evaluate weekly residency within the four zones of the estuary over the period from April 25, 2013, to May 25, 2015. The residency index was calculated as the number of days a striped bass was detected out of the total number of possible days (Afonso *et al.* 2008) where:

$$\mathrm{I_R} = \frac{\#\ of\ Days\ detected}{\#\ of\ possible\ detection\ days} \quad (2)$$

The total number of possible days incorporated time scale of interest (*i.e.* weekly), deployment history of the stations, and individual tag activity (based on tag battery life and period of interest). Due to a limited number of tags active during the spring, all years were pooled.

Departure events were defined as down estuary movement to the confluence with Mira Bay on the Atlantic Ocean, with an absence of detections within the array for 24 hours or greater and followed by subsequent detections ascending the estuary. The start and end of nautical twilight was used to delineate light and dark periods, respectively, and was obtained through the National Research Council Canada sunrise/sunset calculator (NRCC 2018). The Rayleigh Test for uniformity (Zar 2010, Pewsey *et al.* 2013) indicated whether departure and return events were uniformly distributed across multiple temporal scales and if a mean direction existed ($z_{0.05, 13} = 2.937$) thus indicating directed movements were based on time of day.

The wintering period was defined as the first day an individual striped bass was exclusively detected within the wintering aggregation site (stations 11-13) to the first detection on a receiver in the outside array. Array design in 2012 did not allow for detection of striped bass within the wintering site so disappearance from the array during the up-estuary wintering migration was used as an approximate wintering start date. Since striped bass typically left the main aggregation site at Albert Bridge in late autumn to proceed to the wintering site, the last Albert Bridge (Station 7) detection was used to compare start of overwintering across years. The Watson-Williams test for homogeneity was used to determine if mean start and end of overwintering was different across years. The Kruskal-Wallis test was used to determine if there were differences in mean daily water temperature during the up-estuary wintering migration (November and December) and end of wintering (April and May) across years. When statistical differences occurred, the post hoc Dunn Test with Benjamini-Hochberg correction was used for multiple pairwise comparisons (Pohlert 2014).

All analyses were performed using R-statistical software (R Core Team 2013, Ogle 2014) and heavily relied on packages: ggplot2 (Wickham 2009), dplyr (Wickham & Francois 2015), tidyr (Wickham & Grolemund 2017), lubridate (Grolemund & Wickham 2011).

## RESULTS

### Sample Description

A total of 62 striped bass were sampled within the Mira River estuary from July 2012 to November 2014, of which 61 were captured at Albert Bridge while one was captured downstream of Station 17 (Fig 2). Sampled fish ranged in size from 31.6 to 125.0 cm TL and weight from 0.35-20.55 kg (Table 1). Striped bass ages ranged from 2 to 24 years.

The weight-length GMR was:

$$\text{Log W} = 2.929( \ (R2 = 0.9915)$$

where the slope (*b*) is 2.929 (2.55—3.31, 95% CI).

The Von Bertalanffy relationship calculated for the MRe population was:

$$TL_t = 128(1\text{-}e^{-0.12(t - 0.33)}) \text{ where } TL\infty = 128 \text{ cm and } K = 0.12.$$

Striped bass that were acoustically tagged were significantly larger than released non-acoustic tagged fish (Table 1; Welch's t-test; $P < 0.001$).

The acoustic transmitter battery life varied across tag type (Model #, Table 1), thus the number of concurrently active tags within the system varied through time from a low of 5 to a high of 20. Monthly cumulative active transmitters (*i.e.,* number of transmitters active in each month), across years, ranged from a low of 11 in April-May to a high of 30 in November.

From July 2012 to May 2015 there were 1,297,708 acoustic detections registered to tags deployed within the MRe telemetry array. Using the White-Mihoff false filtering technique, 10,101 detections (0.78%) were considered suspect and discarded from analyses. Suspect detections predominantly occurred at aggregation sites within the system (Stations 6, 7, 11, and 13), and were likely the result of signal collisions or two receivers detecting the same transmission concurrently.

### Residency

Residency within the MRe was seasonally concentrated in Zones 2 and 3, with limited residency in Zones 1 and 4 (Fig 6). Overwintering occurred at a winter aggregation site (stations 11, 12 and 13) within Zone 3 from late-autumn (mid-November/early December) through to

**Table 1 Tag information, morphometrics [total length (TL) and weight (W)], and group membership of striped bass acoustically tagged in the Mira River estuary from 2012-2014.**

| Tag ID | Type | Tag life (days) | Date Applied | Activity (days)* | TL (cm) | W (kg) | Group |
|---|---|---|---|---|---|---|---|
| **2012** | | | | | | | |
| 48407 | V13-1L | 793 | Jun-19 | 888 | 61.4 | - | B |
| 48408 | V13-1L | 793 | Jun-19 | 885 | 69.5 | 4.05 | B |
| 48409 | V13-1L | 793 | Jun-20 | 889 | 73.4 | 4.35 | B |
| 48410 | V13-1L | 793 | Jun-20 | 889 | 90.6 | 7.85 | B |
| 48411 | V13-1L | 793 | Jun-20 | 889 | 72.4 | 3.85 | B |
| 48418 | V13-1L | 793 | Jun-26 | 681 | 125 | 19.50 | C |
| 5720 | V13P-1H | 162 | Jun-26 | 143 | 74.4 | 4.35 | A |
| 5721 | V13P-1H | 162 | Jun-26 | 152 | 66.4 | 3.05 | B |
| 5722 | V13P-1H | 162 | Jun-26 | 150 | 63.6 | 3.00 | A |
| 5723 | V13P-1H | 162 | Jun-28 | 150 | 84.4 | - | B |
| 5724 | V13P-1H | 162 | Jul-04 | 144 | 85.6 | 6.75 | B |
| 5725 | V13P-1H | 162 | Jul-06 | 142 | 76.9 | 4.30 | B |
| 5726 | V13P-1H | 162 | Jul-06 | 142 | 77.6 | 5.00 | A |
| 5728 | V13P-1H | 162 | Oct-06 | 57 | 84.4 | 6.55 | A |
| **2013** | | | | | | | |
| 33158 | V13-1L | 881 | Jun-26 | 698 | 69.3 | 3.35 | B |
| 33160 | V13-1L | 881 | Jul-12 | 683 | 75.3 | 4.50 | A |
| 33159 | V13-1L | 881 | Jul-12 | 683 | 63.2 | 2.45 | A |
| 33161 | V13-1L | 881 | Jul-12 | 683 | 63.7 | 3.05 | B |
| 5729 | V13P-1H | 162 | Jul-25 | 179 | 52.8 | 1.50 | B |
| 5730 | V13P-1H | 162 | Jul-25 | 651 | 49.7 | 1.35 | A |
| 33162 | V13-1L | 881 | Aug-13 | 180 | 90.0 | 7.45 | A |
| 5732 | V13P-1H | 162 | Aug-13 | 180 | 79.9 | 6.20 | A |
| 5733 | V13P-1H | 162 | Aug-22 | 180 | 50.0 | 1.35 | A |
| 5734 | V13P-1H | 162 | Aug-27 | 180 | 66.3 | 2.85 | A |
| 5735 | V13P-1H | 162 | Aug-27 | 32 | 69.1 | 3.60 | ** |
| 5736 | V13P-1H | 162 | Aug-29 | 180 | 82.5 | 5.45 | B |
| 5737 | V13P-1H | 162 | Sep-22 | 180 | 51.0 | 1.50 | A |
| 5738 | V13P-1H | 162 | Sep-22 | 180 | 49.9 | 1.30 | B |
| 5739 | V13P-1H | 162 | Nov-11 | 179 | 57.3 | 2.30 | *** |
| **2014** | | | | | | | |
| 5742 | V13P-1H | 162 | Sep-13 | 179 | 61.0 | 2.00 | **** |
| 5743 | V13P-1H | 162 | Sep-13 | 170 | 53.8 | 1.60 | **** |

* Deployment date until last day detected on the array.
** Left estuary 31 days after tagging and did not return.
*** Striped bass tagged too late to definitively resolve movements to the mouth of the system.
**** Telemetry coverage was not in place to resolve migratory group.

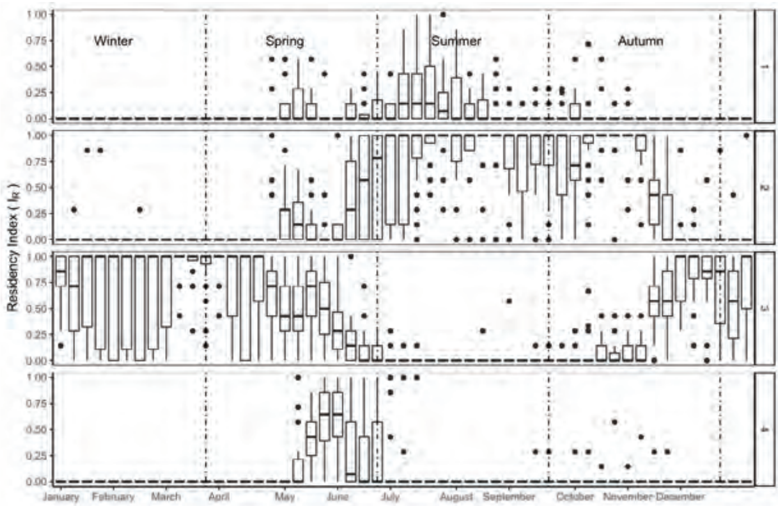


**Fig 6** **Weekly striped bass residency index (IR), pooled across years, in the Mira River estuary from Zones 1-4 during April 25, 2013, to May 25, 2015. Season delineations are based on equinox dates. Vertical bars represent range, boxes one standard deviation and black horizontal bars, mean residency index. Black dots represent receptions of single fish for short periods.**

mid-spring (end of April/first two weeks of May) with median weekly IR ranging from 0.57 to 1.00. December through mid-May weekly median $I_R$ within Zones 1, 2 and 4 was 0.00. Striped bass exhibited residency throughout all zones within the system in mid-spring (Fig 6), however, for two weeks at the end of May-start of June, median IR was greatest (0.64) in Zone 4. Residency shifted to an aggregation area located at the Albert Bridge capture site within Zone 2 at the end of spring. Summer residency was concentrated in Zone 2 at the aggregation site, however, median IR did increase 0.14 in Zone 1 relative to the rest of the year. High residency at Zone 2 persisted throughout the summer and autumn with median IR of 1.00 for all but one week between July and November before striped bass migrated to the up-estuary wintering site in Zone 3.

Seasonal use of the estuary was largely similar among telemetered striped bass, but detection histories suggested three different residency patterns (Fig 7). Group A ($n$ = 12) utilised Zones 2 and 1 during the summer, however, this group made no attempt to leave the estuary–fish were not detected in the Mira Gut channel (stations 1-3) to the Atlantic Ocean. Group B ($n$ = 14) exhibited similar residency patterns, however, this group moved down to the confluence of

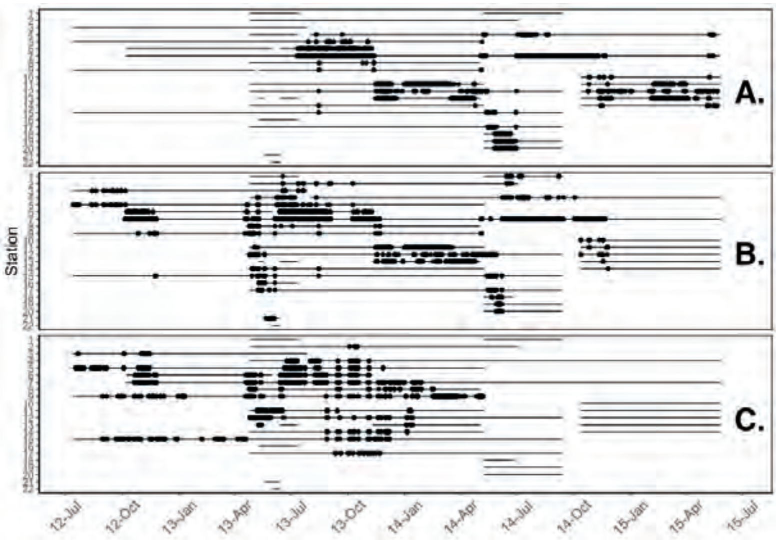


**Fig 7** **System wide activity for three striped bass with multiyear tags within the Mira River estuary: A) ID 33159 exhibits typical residency patterns remaining within the system for the duration of the study. B) ID 48409 exhibits typical residency patterns, but also exhibits departure events. C) ID 48418 exhibits residency, however, it does not overwinter within the winter aggregation site (the only tagged fish to exhibit such behavior). Station deployment history is indicated by horizontal lines.**

the estuary with the ocean, and, in some instances left the system. Group A typically exhibited greater $I_R$ throughout the system than group B (Fig 8), but most notably during spring and summer residency of Zones 4 and 1, respectively. Greater $I_R$ values could, however, be a result of greater number of tags active within group B. Median residency in Zone 4 increased concurrently for both groups, but Group A peaked ($I_R$ 1.00) one week earlier than Group B ($I_R$0.71) and maintained high levels of residency through the second week of July, while Group B departed Zone 4 by the second week in June. Residency index in Zone 1 peaked early in the summer for both groups, but median $I_R$ for Group A reached 0.71 while Group B only exhibited an $I_R$ of 0.14. Both groups, however, exhibited annual seasonal fidelity (high and relatively exclusive $I_R$) to summer and winter aggregation sites (Fig 8). There was no significant length difference between the two groups (*Welch's test*; $P = 0.758$, df: 24).

Group C consisted of one fish (ID 48418; Fig 7) that was 125.0 cm TL. This striped bass did not aggregate at the wintering site and was found throughout Zones 2 and 3 during the winter and spring but

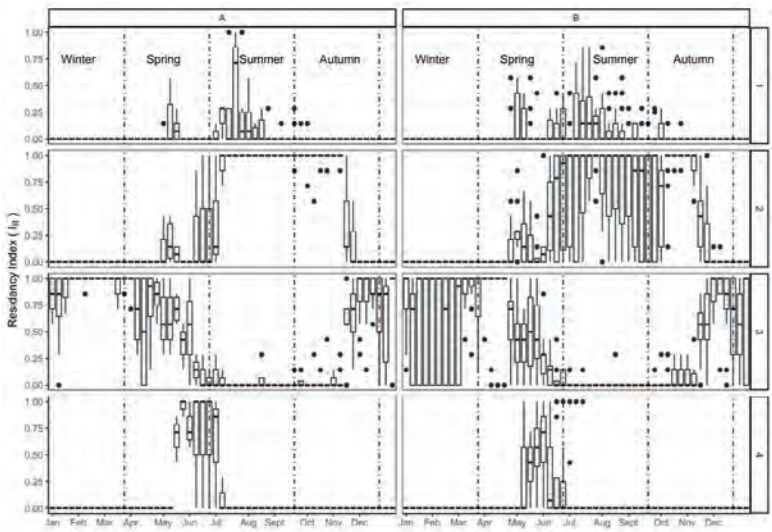


**Fig 8** **Weekly striped bass residency index (IR), pooled across years, for migratory groups A (left) and B (right) from Zones 1-4 in the Mira River estuary during April 25, 2013, to May 25, 2015. Season delineations are based on equinox dates. Vertical bars are range, the box one standard deviation, and the horizontal bar, mean residency time.**

summer residency was concentrated within Zones 1 and 2, like groups A and B. Autumn residency, however, occurred throughout the entire system including Zone 4. While this striped bass was detected in the channel leading to the ocean, it did not exhibit departure events.

## Departure Events

Due to logistical challenges, no receivers were deployed in Mira Bay, however, directed down estuary movements, a lack of detections within the array, observations of striped bass descending past a wharf at the mouth of the system (CFB, personal observation), and angler reports of capture events outside the river mouth (John Couture, local angler; Pat Young, DFO; personal communication) indicated the occurrence of departure events. One telemetered striped bass (ID 5735) left the estuary, 31.8 days post tagging, and was not subsequently detected within the MRe array. Despite proximity to OTN, Bras d'Or Lakes, Canso Strait, and Halifax receiver arrays, no telemetered striped bass from MRe were detected by the telemetry infrastructure in the region (Fig 1).

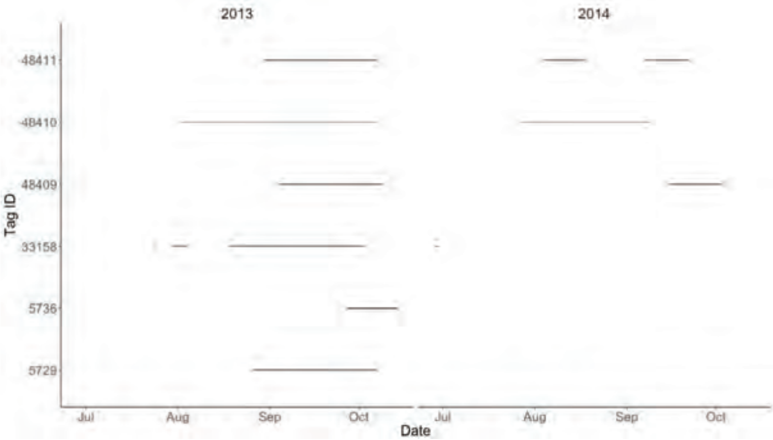


**Fig 9 Gantt chart of striped bass departure events in the Mira River estuary (n = 13). Horizontal lines indicate time spent outside of the system by each acoustically tagged individual (tag ID).**

Six fish exhibited 13 departure-return events during 2013 and 2014 (Fig 9). Four striped bass with multiyear tags displayed departure-return events across the two years, two of which exhibited multiple events within years. Departure and return events were not random for day of the year (Rayleigh Test for uniformity, $P < 0.001$) and occurred between June and October with mean exit and return dates of August 17th ± 25 days (mean ± SD) and September 14th ± 33 days, respectively. Striped bass left the MRe for 26.5 ± 20.1 days (mean ± SD), however, fish that exhibited multiple within-year departure events had highly variable absences (Fig 9). Striped bass exit-return events were not uniformly distributed by time of day (Rayleigh Test for uniformity, $P < 0.001$), primarily occurring at night. One departure event occurred in the morning (after the start of twilight, but before sunrise), while one return event occurred mid-day. All other departure and return events occurred at night (Fig 10). Mean exit and return times were 0225 UTC ± 1.8 hours (mean ± SD) and 0521 UTC ± 3.1 hours, respectively. Length of striped bass that exhibited departure events ($n = 6$) was not significantly different (Wilcoxon Rank Sum Test, $P = 0.4093$) than those that remained within the MRe (n = 24). The remainder of acoustically tagged fish remained within the estuary for the duration of their tag battery.

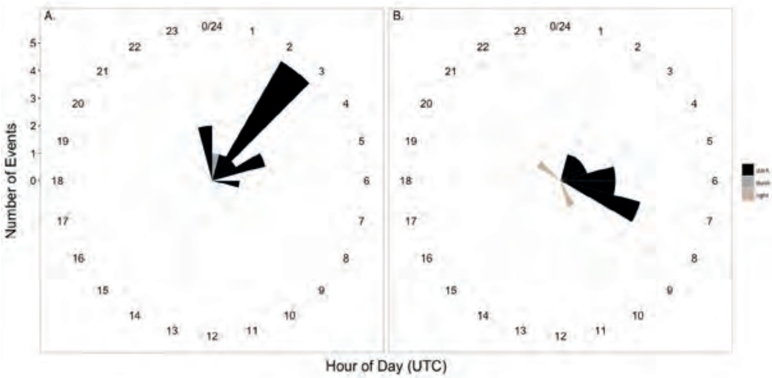


**Fig 10** **Timing of striped bass departure (A) and return (B) events in the Mira River estuary. Colour of bars indicate light levels at time of departure/ return event (black = dark, grey = dusk, tan = light). Length of bars indicate number of events to occur within the hour.**

## Overwintering

Of the 31 telemetered striped bass, 30 overwintered within the MRe between 2012 and 2015 and 29 occupied the mid-estuary wintering site (Fig 2, Stations 11-13). Migrations for wintering occurred from Albert Bridge (Station 7) tagging site to the wintering site 5.5 km up estuary, starting mid-November and ending by the first week of December (Table 2). The up-estuary migration lasted 3.22 ± 5.21 and 1.26 ± 1.08 days (mean ± SD) for 2013 and 2014, respectively. The wintering period lasted until the end of April and into May with a duration of 160.19 ± 11.05 days (mean ± SD). Wintering duration was shortest for the winter of 2012-2013 with start and end dates later and earlier, respectively, than the following winters (Table 2). The mean date of departure from Albert Bridge for overwintering in 2012 was significantly different from the following winters 2013 and 2014, (Watson-William's test; $P < 0.05$), but no significant difference was observed between mean date of departure and arrival at the wintering site for 2013 and 2014 (Table 2). The mean wintering period end date was significantly different across all three years (Watson-Williams test; $P < 0.05$) and was later in each of the three successive springs (Table 2).

Daily mean water temperature during the November and December winter migration (Fig 11) was significantly different across years (Kruskal-Wallis $\chi^2$ 13.48, df = 2, $P$ = 0.0012). *Post hoc* multiple pairwise comparison indicated that 2012 was significantly

**TABLE 2 The timing of yearly striped bass migrations from Albert Bridge aggregation site to the wintering site and departure from the wintering site in Zone 3 of the Mira River estuary from 2012–2015. Units for standard deviations are days. Dates within the same column with different superscript letters were significantly different (Watson-Williams test; $P < 0.05$).**

| | | Last Albert Bridge | Start of wintering | | End of wintering | | | Duration |
|---|---|---|---|---|---|---|---|---|
| **Winter** | **N** | **(mean ± SD)** | **mean ± SD** | **Range** | **N** | **mean ± SD** | **Range** | **mean ± SD** |
| 2012-2013 | 13 | Nov. 24 ± 3.71[a] | Nov. 25 ± 3.32* | Nov. 16-Dec. 02 | 5 | Apr. 20 ± 3.21[d] | Apr. 18-Apr. 26 | 146.28 ± 3.56 |
| 2013-2014 | 19 | Nov. 15 ± 4.13[b] | Nov. 19 ± 5.40[c] | Nov. 12-Dec. 05 | 11 | May 01 ± 6.10[e] | Apr. 24-May 12 | 163.46 ± 9.45 |
| 2014-2015 | 11 | Nov. 19 ± 4.37[b] | Nov. 23 ± 6.07[c] | Nov. 10-Dec. 02 | 5 | May 09 ± 2.65[f] | May 06-May 13 | 166.91 ± 6.84 |

* The wintering site acoustical array was not deployed for the winter of 2012-2013 thus the last detection on the Albert Bridge array was used as overwinter start date and the results could be compared to following years.

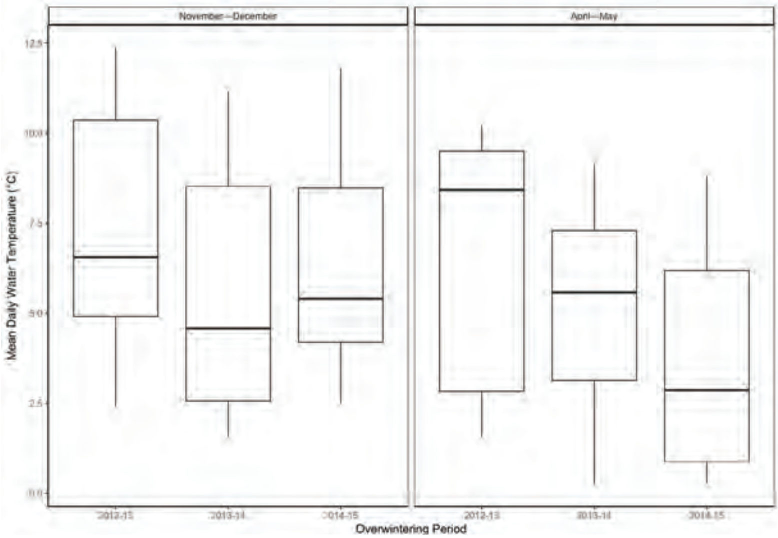


**Fig 11 Boxplot of mean daily water temperature recorded at Albert Bridge during the months at the start (left) and end (right) of the striped bass overwintering period in the Mira River estuary across three years. Range is indicated by vertical lines, mean, by horizontal line. Letters indicate significant differences from multiple pairwise comparisons between temperatures within the panel (Dunn Test, α = 0.05).**

different (a, warmer) than 2013 and 2014 (Dunn Test; $P = 0.0008$ and $P = 0.0350$, respectively), however, 2013 was not different from 2014 (b, Dunn Test; $P = 0.1721$). Temperature differences also occurred across years at the end of the wintering period during April and May (Kruskal-Wallis $\chi^2$ 26.87, df = 2, $P < 0.0001$) and followed a similar pattern to the end of overwintering date (Table 2) with successive springs colder than the previous. Mean daily water temperature for April and May 2013 was significantly warmer than for 2014 and 2015 (c, Dunn Test; $P = 0.0282$ and $P < 0.0001$, respectively), while 2014 was warmer than 2015 (d, Dunn Test; $P = 0.0044$).

## DISCUSSION

### Population Characteristics

Size structure of striped bass sampled in the Mira River estuary exhibited differences relative to historical data from other Canadian stocks. Reported length frequencies for the Shubenacadie-Stewiacke and Miramichi rivers contained few larger individuals (>90 cm TL;

Robichaud-Leblanc *et al.* 1996, Douglas *et al.* 2009, Bradford *et al.* 2012), however, studies in the Annapolis and Saint John Rivers in the outer Bay of Fundy, indicate that large individuals were present (Rulifson & Dadswell 1995, Dadswell *et al.* 2018, Andrews *et al.* 2019b). More recent trap-net catch data from the Shubenacadie and Miramichi rivers (Douglas *et al.* 2003, DFO 2017) are consistent with historical data with length frequencies not exceeding 90 cm TL. A negative size bias may be associated with these trap net data as anglers report large striped bass (females to 121 cm TL and males to 97 cm TL) were frequently caught on the spawning grounds in these rivers (Owen Marr, local angler; personal communication; S.N. Andrews, personal communication). Similarly, the absence of size classes < 30 cm TL in the MRe is probably a result of our gear, bait size, and angling site selectivity.

All but one of the sampled striped bass were captured at the Albert Bridge sampling site but only one small fish (33.2 cm TL) was captured there. The striped bass not captured at Albert Bridge was 31.6 cm TL and was caught 14 km up-estuary. This is consistent with reports of 20 to 30 cm striped bass caught during the early 2000's in a small tributary 10 km up-estuary from Albert Bridge (Cruise Slater, local resident; personal communication). It is not surprising that there is a lack of captures of small fish given typical ontogenetic shifts in estuarine habitat reported for striped bass (Robichaud- LeBlanc *et al.* 1998, Able & Grothues 2007). Our sampling, however, was prioritized for the deployment of acoustic tags.

**Residency within the Mira Estuary**

Residency and fidelity to summer and winter aggregation sites was evident across years throughout the study period. This behaviour was typical for striped bass containing acoustic tags with both half-year and multiyear battery life. Evidence for residency and fidelity beyond the telemetry study was obtained through tag returns from recreational anglers. Acoustic transmitters were returned up to three years post release. In one instance a recaptured fish (ID: 33161) was caught October 22, 2015 at Albert Bridge, two years to the week after initial tagging; then harvested from the same site one year later, on October 25, 2016 (C. Paul, Unama'ki Institute of Natural Resources; Joe Sylvester, local angler; personal communication). Acoustic telemetry of striped bass in the MRe revealed interannual residency, site fidelity, seasonal movements, and contingent behaviour consistent with populations elsewhere in the range (Rulifson & Dadswell 1995, Wingate *et al.* 2011, Gahagan *et al.* 2015, Andrews *et al.* 2018), and, with the presence of a critical overwintering site, potential spawning, and foraging habitat, suggests the MRe population may constitute a discrete stock.

All telemetered striped bass that exhibited residency in the MRe remained within the mid-estuary throughout the winter and, of these residents, all but one utilized the mid-estuary wintering site across years. The up-estuary migration for wintering was spatially and temporally limited compared to other striped bass populations consisting of only a 5.5 km up estuary movement over 1-3 days between mid-November and the first week in December. Winter residency in the Mira, however, was among the longest known throughout the striped bass range persisting into the first week of May (Andrews *et al.* 2019c). Kneebone and co-workers (2014) observed mixed stock wintering migrations of 300 to 700 km southward from Massachusetts in November with striped bass arriving at coastal and estuarine overwinter sites in the Chesapeake Bay and Hudson Rivers by December. These telemetered fish are detected moving into spawning rivers by late February and early March. A freshwater overwintering contingent (Paramore & Rulifson 2001) within the Bay of Fundy's Shubenacadie population migrates a minimum of 50 km into Grand Lake from October through November (Bradford *et al.* 2012) where they remain until May (Douglas *et al.* 2003). A marine overwintering contingent, however, remains within the Minas Passage of the inner Bay of Fundy from December through March (Keyser *et al.* 2016). In the Saint John River, NB, the OWS occurs primarily in Belleisle Bay, an estuarine lake, and lasts from mid-October until April (Andrews *et al.* 2020). In the Kouchibouguac River, 50 km south of the Miramichi R., striped bass overwinter from December through the start of April (Bradford *et al.* 1998). Miramichi River striped bass migrate back to their natal estuary from around the sGSL to overwinter from late fall to early May; non-natal estuaries across the sGSL are opportunistically used as wintering sites (Rulifson & Dadswell 1995, Bradford *et al.* 1998, Douglas *et al.* 2003, Buhariwalla *et al.* 2016) with returns to the Miramichi (often > 350 km) occurring in May (Douglas *et al.* 2009, S. Douglas, DFO, personal communication, CFB, unpublished data). The historical St. Lawrence River population had migrated to freshwater wintering sites near spawning sites, approximately 400 km upriver, beginning in late September to early October where they remained until spring spawning in mid-May (Magnin & Beaulieu 1967, Robitaille *et al.* 2011). The observed latitudinal variation in overwintering timing and duration across the range is thought to be a function of water temperature and salinity as osmoregulation at lower temperatures and high salinities is metabolically expensive resulting in the requirement for winter refugia (Hurst & Conover 2002).

Previous studies indicate the use of a wide variety of overwintering habitat among and within stocks. Gahagan and co-workers (2015) demonstrated that striped bass overwintered in the lower Hudson River estuary and nearby coastal waters. Shubenacadie-Stewiacke River striped bass (Bay of Fundy) utilize freshwater (Rulifson & Dadswell 1995, Bradford 2012) and marine (Paramore & Rulifson 2001, Keyser *et al.* 2016) winter habitat, while estuarine and freshwater overwintering is common throughout the southern Gulf of St. Lawrence (Rulifson & Dadswell 1995, Bradford *et al.* 1998). Striped bass also overwinter in warmwater discharges from power generating plants throughout its range (Williams & Walden 2010, Buhariwalla *et al.* 2016). The MRe wintering site was likely used since it was a deep embayment with relatively stable temperatures (~5-10°C) through much of the winter (Coutant 1985), and since it was protected from cool waters of the shallow section of estuary above, and from the cold tidal waters down estuary. Given the west-east orientation of the wintering site, and many small islands to the north and to the shore to the south, the site remained relatively protected from autumn southwesterly and winter northerly winds (especially after ice formation). A lack of turnover allowed water column stratification to persist as surface water air cooled and surface salinity was dominated by runoff and river flow resulting in the mid to lower strata retaining trapped heat while dominated by intermediate salinities. At the end of the winter, however, the wintering site did turn over.

**Spring Residency**

After the overwintering period, residency from mid-May to early July was highest in the upstream (Zone 4) freshwater portion of MRe. Outside of land-locked reservoir populations, spring freshwater use is typically associated with spawning activity (Setzler-Hamilton & Hall 1991, Wingate *et al.* 2011), with residency in the MRe coinciding with the spawning period reported for northern populations (Setzler *et al.* 1980, Dunston *et al.* 2018, Andrews *et al.* 2019b). Spawning in the Shubenacadie-Stewiacke system occurs from late May through mid-June (Rulifson & Tull, 1998, McInnis 2012). In the Miramichi River, the closest recognized stock to the MRe, spawning occurs for 3-4 weeks in late May through late June (Robichaud-LeBlanc *et al.* 1996, Douglas *et al.* 2009). No spawning behavior was observed, and no eggs or larvae were collected in the MRe (CFB, unpublished data), however, we observed one running ripe male and three spent females that were captured by anglers and anglers reported milting striped bass in the freshwater zone after our fieldwork was completed (K. Hutchins and A. Hunt, personal communication). It is not possible to say for certain if spawning occurs within the MRe, but patterns of residency match those of spawning populations whereby overwintering is followed by migrations to and residency in freshwater with subsequent migrations to summer foraging sites.

**Summer/Autumn Residency**

Residency of MRe fish shifted to Albert Bridge (Station 7) and to a minor extent, the lower estuary from summer through late autumn. Annual fidelity of striped bass to summer feeding sites is widely documented (Ng *et al.* 2007, Wingate & Secor 2007, Mather *et at.* 2009, Kneebone *et al.* 2014) and estuarine distribution is often associated with shoreline or bathymetric structure and strong currents. Striped bass tend to concentrate around artificial structures such as bridge pilings and associated shoreline anchor stone (Haeseker *et al.* 1996), natural structure of submerged woody debris (Wilkerson & Fisher 1997), mussel and oyster beds (Harding & Mann 2003), and/or bathymetric relief (Ng *et al.* 2007). The MRe summer aggregation site occurred where the system narrows from ~ 1000 m across and 14-19 m depth (both up and downstream) to a 100 m long stretch that is 80 m wide and 3-10 m deep. Bridge pilings, associated anchor stone, natural rock bars, and oyster beds resulted in diverse physical structure and combined with tidal currents, concentrated striped bass. Summer residency also occurred, to a lesser extent, in the lower MRe as half of tagged fish moved down estuary to the confluence with the Mira Bay/Atlantic Ocean. A small subset of these fish left the system for up to two months, however, they returned to the Albert Bridge aggregation site until the fall migration to the wintering site. Different summer residency strategies among telemetered striped bass indicate that complex migratory behaviours, typical of populations elsewhere, also occur within the MRe.

**Contingent Behaviour**

Striped bass contingent behaviour is an excellent example of partial migrations (Chapman *et al.* 2012, Gahagan *et al.* 2015), whereby multiple migratory strategies exist within or between populations. For example, the Chesapeake Bay and Hudson River stocks are comprised of three contingents: freshwater, estuarine, and coastal migratory contingents as defined by habitat used by post-spawning adults (Secor & Piccoli 2007, Wingate & Secor 2007, Wingate *et al.* 2011). Coastal migratory contingents are further complicated by sub-groups that exhibit residency and often express annual site fidelity in non-natal estuaries (Mather *et al.* 2009, Grothues *et al.* 2009, Patzuke *et al.* 2010, Kneebone *et al.* 2014, Andrews *et al.* 2018). Able & Grothues (2007) found that some coastal migrants occupied the Mullica River-Great Bay, New Jersey and Saco River, Maine estuaries from spring through late autumn. In a concurrent mobile telemetry study non-natal migrants were identified that exhibited annual residency and site fidelity on a scale of several meters within the Mullica River-Great Bay system (Ng *et al.* 2007). These non-natal residents typically return to natal systems (or nearshore coastal environment) in autumn to prepare for the spring spawning run (Mather *et al.* 2010, Kneebone *et al.* 2014, Gahagan *et al.* 2015). Some individuals, however, remain in non-natal systems year-round only returning to spawning sites in the spring, then promptly returning to the non-natal system (Andrews *et al.* 2018).

The contingent behaviour and partial migrations which occurred within the MRe appeared like those found within other stocks. Three distinct groups were observed in the MRe: groups A ($n$ = 12) and B ($n$ = 14) followed the cycle of overwintering at the main aggregation site, spring freshwater residency, autumn residency at the lower-estuary aggregation site, and then migration back to the wintering site. Group A remained within the estuary and made no excursions to the mouth of the system. Group B ventured to the mouth of the system with some individuals ($n$ = 6) exiting the system for up to two months. Group C ($n$ = 1) remained within the mid- to lower-estuary but did not occupy the main winter aggregation site and did not leave the system. These groups may represent A) estuarine residents, B) a mixture between estuarine residency and local marine residency, and C) undefined since only one individual exhibited this behaviour. Given that these fish remained within the system during winter, exhibited spring and summer freshwater residency (groups A and B), and those that made marine departures returned by mid-autumn, it appears that the MRe striped bass are local in origin and may constitute a spawning stock even though genomic analysis of MRe fish suggested they have a mixture of US and Miramichi genotypes (Leblanc *et al.* 2020).

Contingent behaviour in other coastal ecosystems perhaps suggest migratory groups exist within the MRe (*e.g.* freshwater residents, coastal migrants). These groups, if present, were unlikely to be intercepted and sampled in our study given the timing and location of our sampling was June through November at one site in the lower estuary. A potential freshwater contingent would remain in the headwaters of the system until down-estuary migration to wintering sites (Wingate & Secor 2007), while a migratory contingent would move to the ocean immediately after freshwater spawning (Douglas *et al.* 2009, Gahagan *et al.* 2015). The best chance to sample these potential contingents would either be on the wintering grounds or during upstream spring spawning migrations, however, with exception of using dorsal colouration as an identifier of marine overwintering (Paramore & Rulifson 2001), differentiation between contingents would have been nearly impossible at the time of our sampling. A migratory contingent was not encountered during the spring alewife (*Alosa pseudoharengus* Wilson, 1811) fishery in the lower estuary (J. Horne, K. Nichols, commercial alewife fishers; personal communication), however, there are several explanations for this: 1) gill mesh size used in the MRe is not selective for spawning size striped bass (Trent & Hassler 1968); 2) the commercial alewife season ends by early June and does not overlap with a seaward return migration period of mid- to late- June, based on spawning activity in the Miramichi River, NB (Douglas *et al.* 2009) and timing of MRe freshwater residency.

### Departure Events

Departure events in the MRe occurred in late July through late September following residency at the Zone 1 estuarine aggregation site. All but one striped bass, which left the system and was possibly captured or predated while outside the MRe, returned to the aggregation site at Albert Bridge by early October. Time of return coincides with the start of migrations to wintering sites by migratory contingents of other striped bass stocks (Mather *et al.* 2010, Pautzke *et al.* 2010, Kneebone *et al.* 2014). Unlike in MRe, however, estuarine egress of these contingents occurred soon after spawning (Douglas *et al.* 2009) and was often associated with summer foraging (Boreman & Lewis 1987, Mather *et al.* 2009). The Mira River estuary departure events appear to be associated only with foraging behaviour.

Striped bass were observed feeding on Atlantic mackerel (*Scomber scombrus* Linnaeus, 1758) at the Albert Bridge aggregation site in late July and early August (CFB, personal observation). Alosid predation is also common throughout the striped bass range (Walter *et al.* 2003) and departure events possibly coincided with juvenile alewife and blueback herring (*Alosa aestivalis* Mitchill, 1815) out-migrations, which typically occur from August through October (Stokesbury & Dadswell 1989, Iafrate & Oliveira 2008, Greene *et al.* 2009). Ng and co-workers (2007) observed that maximum daily movements of striped bass in Mullica River-Great Bay estuary were concentrated around sunset; however, we found that departure events occurred predominantly at night (after twilight hours), which is when juvenile alewife and blueback herring out-migrate to sea (Greene *et al.* 2009). Alternatively, observed preference for nighttime departure and return events may be associated with predator avoidance since Mira Bay is populated with many piscine predators including American bald eagles (Cash *et al.* 1985), osprey, sharks, and seals.

Documented departure events may have been negatively biased due to a lack of receiver coverage in Mira Bay owing to logistical challenges associated with highly mobile sediment upwards of 900 m from the mouth of MRe. The group classified as using the channel leading to the Mira Bay were defined to depart from the system based on a lack of detections in the array for > 24 hours followed by sequential up estuary detections. Thus, departure events for < 24-hour periods are not resolvable by our methods. Given the lack of detections from other nearby receiver arrays striped bass that left the MRe probably remained in the relatively local area of Mira Bay (Bigelow & Schroeder 1953).

## Interactions with Other Telemetry Infrastructure

The OTN acoustic telemetry infrastructure in the Canadian Atlantic region with receiver arrays in the Cabot Strait, Bras d'Or Lake, Strait of Canso, and off Halifax, among others in the sGSL and further afield (Bangley *et al.* 2020), would have detected MRe striped bass if they had embarked on northerly or southerly long distance coastal migrations. Similar arrays in the Bay of Fundy and New England coasts often detect migrating striped bass throughout the year as they embark on coastal migrations and exhibit residency in non-natal estuaries (Grothues *et al.* 2009, Mather *et al.* 2010, Kneebone *et al.* 2014, Andrews *et al.* 2017). Throughout our study striped bass tagged in the Mira River estuary remained local freshwater, estuarine, and marine residents.

## CONCLUSIONS

Evidence that striped bass stocks at the northern extreme of their range in Nova Scotia have adapted to isolated freshwater watersheds is demonstrated by both past and recent evidence. Anglers in the past have captured numerous record fish in this region from Porters Lake near Halifax north to the Mira estuary (NSDFA 2007, NSDFA 2018, Andrews *et al.* 2019a). Annually there have been reports of large concentrations of juvenile striped bass in local estuaries (Andrews *et al.* 2019a). During exploratory investigations we made before the MRe study we tagged striped bass in the Fourchu area, Cape Breton Island, south of the MRe. Since then, we have had our tags reported by anglers from that area and only that area (CFB, unpublished data). Abundant tagging data from the striped bass stock in the Shubenacadie River, Nova Scotia, indicates fish predominately remain in Minas Basin (Broome 2014). We suggest that striped bass have established isolated, local populations in eastern Nova Scotia like those at the southern extreme of their range (Hess *et al.* 1999, Bjorgo *et al.* 2000, Nelson *et al.* 2010), which complements our understanding of the species biology in the Canadian Maritimes and may be associated with common behavior among stocks near the extents of its range. Critical habitat for establishment of a stock in the Maritimes includes an appropriate wintering site, a spawning site and availability of desired prey. We continue to study this aspect of striped bass biology in Nova Scotia and hope to report further findings in the future.

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# DIVERSITY OF MYCORRHIZAL FUNGI IN EASTERN HEMLOCK STANDS WILL SIGNIFICANTLY CHANGE WITH THE EFFECTS OF HEMLOCK WOOLLY ADELGID INFESTATION IN SOUTHWESTERN NOVA SCOTIA, CANADA

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## ABSTRACT

A foundation tree species, eastern hemlock (*Tsuga canadensis*) is threatened by the invasive hemlock woolly adelgid (*Adelges tsugae*) (HWA) in southwestern Nova Scotia, Canada. The loss of this key species and its heavily shaded ecosystems may alter the diversity of important mycorrhizal fungi in hemlock forests. Mycorrhizal fungi share a vital mutualistic relationship with their host trees; consequentially, understanding if and how the predicted eastern hemlock decline will affect mycorrhizal diversity is paramount. Using available literature, we discuss three major consequences of HWA on eastern hemlock ecosystems – changing forest composition, loss of old-growth trees, and increased insect stress on host trees – and how they will likely influence mycorrhizal communities as adelgid infestations intensify. Environmental variables are also discussed as another major influence on fungal diversity. We conclude that the mycorrhizal community of eastern hemlock forests will likely change significantly as old-growth

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hemlock is replaced with mixed forest. We also suggest that mycorrhizal community composition will shift in favour of generalist mycorrhizae which form symbioses with multiple tree species. These conclusions illuminate the future of hemlock forest fungi in southwestern Nova Scotia and underline the importance of conserving old-growth eastern hemlock forests and their unique fungal communities.

Keywords: Eastern hemlock, Hemlock woolly adelgid, Mycorrhizal fungi

## INTRODUCTION

Eastern hemlock (*Tsuga canadensis*) is a foundational tree species of Acadian or Wabanaki forest (Ellison *et al*. 2005, Ellison 2014, Parks Canada 2021). Widespread across eastern North America (Godman & Lancaster 1990, Ellison 2014), this species is often found growing in monoculture stands (Goerlich & Nyland 2000, Ellison *et al*. 2005) and matures slowly, sometimes achieving lifespans of 800 years or more (Godman & Lancaster 1990). Eastern hemlock creates distinctive environmental conditions – in particular, its thick, shady canopies reduce temperatures on the forest floor by restricting light levels (Canham *et al.* 1994, Hadley 2000). In addition, its fallen needles decompose slowly (Cobb *et al*. 2006) leading to low rates of nutrient cycling and calcium mineralization (Finzi *et al.* 1998a, b, Jenkins *et al*. 1999, Dijkstra 2003) and acidic soils which are rich in organic material (Mladenoff 1987, Finzi *et al*. 1998a, b, Fassler *et al*. 2019). Eastern hemlock stands host a unique ecosystem (Ellison 2014) which is dependent on the distinctive environmental conditions provided by this tree species. As such, eastern hemlock is considered a forest foundation species (Ellison *et al*. 2005) without which the associated ecosystem could not survive. Furthermore, recent declines of eastern hemlock due to an invasive pest are concerning ecologists throughout eastern North America.

The hemlock woolly adelgid (*Adelges tsugae*) (HWA) is a tiny, aphid-like insect which attaches to the base of hemlock needles and feeds on the xylem ray parenchyma, causing needle loss and eventual branch or tree mortality with large infestations (Orwig & Foster 1998). Native to East Asia and the Pacific Northwest of North America, HWA was first detected in the southeastern United States in the 1950s, likely introduced from a southern Japanese population (Stoetzel 2002, Havill *et al*. 2006, 2016, Crandall *et al*. 2022), and has been moving north ever since. HWA is particularly destructive for eastern hemlock because this pest has no natural insect predators in eastern North America, unlike in its native ranges in Asia and western North America (Sasaji & McClure 1997, Kohler 2007, Crandall *et al*. 2022). Further, eastern hemlock appears to have little to no natural immunity to HWA (Ingwell & Preisser 2011). A heavy HWA infestation can kill a mature eastern hemlock tree in 4-10 years (McClure 1991, Orwig *et al*. 2002) and can prevent stand regeneration by damaging saplings below infested canopies (Orwig & Foster 1998). Many of the organisms in eastern hemlock ecosystems may be affected by the loss of this foundation species, including one group which is often overlooked, yet crucially important to these ecosystems: fungi.

Forest ecosystems as we know them could not exist without forest fungi. These important decomposers and mutualists facilitate nutrient cycling in the ecosystem by liberating nutrients trapped in organic and inorganic material, which can then re-enter the food web (Hobbie *et al*. 1999, Fukasawa 2011, Shortle & Smith 2015). Many fungi form mutualistic associations with plants and trees (Egli 2011, Lindahl & Tunlid 2015, Sapsford *et al.* 2017). These are known as mycorrhizal fungi, or mycorrhizae, and nearly all land plants form associations with them (Wang & Qiu 2006, Willis *et al*. 2013, Jacquemyn & Merckx 2019). Evolved from saprobic fungi (Kohler *et al*. 2015, Lindahl & Tunlid 2015), which break down dead organic material, mycorrhizal fungi form mutualistic partnerships with plant roots to trade water and nutrients scavenged from the environment for photosynthetic sugars produced by the host plant. There are two main types of mycorrhizae that associate with trees: ectomycorrhizae (ECM) and arbuscular mycorrhizae (AM). Ectomycorrhizae form branching structures called Hartig nets around and between the cortical cells of the host tree's fine roots, which they use to interface with the tree and exchange resources (Nehls 2008). Many conifers, including eastern hemlock, and some hardwoods commonly associate with ECM (Molina *et al*. 1992). Arbuscular mycorrhizae also interface with the root cells of a host tree; however, rather than extracellular Hartig nets, these fungi form tree-like structures called arbuscules inside root cortical cells – this is why AM are also considered *endo*-mycorrhizae. Arbuscular mycorrhizae are much more common than ECM, colonizing hardwood trees such as maple and ash, and most herbaceous plants (Molina *et al.* 1992, Willis *et al*. 2013). They also show less preference for a particular host species, and are therefore considered generalists (Moora *et al.* 2011). Both types of mycorrhizae can be found in most forest ecosystems, including in those of southwestern Nova Scotia.

The landscape of southwestern Nova Scotia consists of rolling hills of Wabanaki mixed forest, frequently interspersed with lakes and rivers (Polach 1992). Much of this area is part of the Southwest Nova Biosphere Reserve – a UNESCO-designated reserve which is made up of crown lands, wilderness areas, nature reserves, national and provincial parks, and transition zones (Southwest Nova Biosphere 2023). This reserve includes the Tobeatic Wilderness Area and Kejimkujik National Park and National Historic Site, which contains some of the largest old-growth eastern hemlock stands in the province (Parks Canada, pers. comm. 2022). HWA was detected in southwestern Nova Scotia in 2017 and was likely present for about 10-15 years prior to its discovery (Parks Canada, 2021, Parks Canada, pers. comm. 2023). While conservation efforts are ongoing, unfortunately, researchers predict that up to 80% of eastern hemlock in southwestern Nova Scotia will be lost to this insect pest by 2030 (Parks Canada 2021). This may have profound consequences for the hemlock ecosystems in this region.

Mycorrhizal diversity in southwestern Nova Scotia is currently undocumented but is being studied by the authors of this essay. Since mycorrhizal fungi play important roles in sustaining long-term forest communities, any changes in fungal diversity and abundance can have profound effects on forest health and regeneration (O'Brien 2009, Talbot *et al.* 2014); therefore, it is crucial to understand if and how these mycorrhizal communities will be altered by forest disturbances. Mycorrhizal communities in eastern hemlock forests may be greatly impacted by HWA in several ways. Altered forest composition, loss of old-growth trees, and increased insect stress on host trees are all consequences of HWA which will likely affect fungal diversity. Environmental changes caused by pollution and by shifts in forest conditions may also have an important influence on mycorrhizal diversity and should be considered to gain a more complete understanding of mycorrhizal dynamics (Egli 2011, Sapsford *et al.* 2017). In this essay, we use the available literature to discuss the effects of three major factors related to HWA invasion – changing forest composition, loss of old-growth trees, and increased insect stress – on the mycorrhizal diversity of eastern hemlock stands. The effects of altered environmental variables on forest fungi are also considered. Finally, we discuss the significance of shifting mycorrhizal diversity and how changes in these key fungal communities may influence the forests of southwestern Nova Scotia as HWA infestations progress.

## DISCUSSION

The increasing diversity of tree and plant species within historically hemlock-dominated stands may significantly alter mycorrhizal community diversity in the forests of southwestern Nova Scotia. Forest fungal communities are very sensitive to vegetation changes (Packham *et al*. 2002, Landi *et al*. 2015) and their diversity is mainly driven by forest succession and composition (Dighton *et al*. 1986, Last *et al*. 1987, Rineau *et al*. 2010, Spake *et al*. 2016, Tomao *et al*. 2020). Accordingly, the diversity of both ECM and AM are very likely to shift in southwestern Nova Scotian forests as eastern hemlock is replaced by other conifer and hardwood tree species. Some diversity may be lost because certain ECM can only associate with specific tree species (Molina *et al*. 1992, Dickie *et al*. 2009, Tomao *et al*. 2020). As hemlock stands decline, any ECM which rely solely on eastern hemlock will likely not survive; for example, stipitate hydnum fungi (toothed fungi) are generally hemlock-associated ECM, many members of which are in danger of regional extinction due to hemlock loss (Baird *et al*. 2013). Additionally, Fassler *et al.* (2019) suggest that ECM diversity becomes simplified and homogenized after eastern hemlock forests decline; however, the hemlocks in this study – conducted in western Massachusetts, USA – were replaced mainly by black birch (*Betula lenta*), which is absent in Nova Scotia. Instead, the hemlock stands in southwestern Nova Scotia will most likely be replaced by many different tree species; for example, in Kejimkujik National Park and National Historic site, eastern hemlock forests were replaced by white birch (*B. papyrifera*), red maple (*Acer rubrum*), Balsam fir (*Abies balsamea*), red and black spruce (*Picea rubens*, *P. mariana*), and white pine (*Pinus strobus*) after outbreaks of pale-winged grey moth (*Iridopsis ephyraria*) in 2002-2006 caused severe defoliation of eastern hemlocks (Hervieux 2013, Parks Canada, pers. comm. 2023). Tree species diversity and ECM diversity are positively related (Kernaghan *et al.* 2003, Cavard *et al.* 2011);

therefore, the ECM diversity of southwestern Nova Scotian forests may actually increase as hemlock-dominated stands are replaced with mixed forest, despite losing certain hemlock-dependent ECM species. Moreover, the abundance and diversity of AM are likely to increase as the forest canopy opens and more hardwood species and herbaceous plants move in with the increased light, outcompeting the slow-growing hemlock seedlings (Battles *et al.* 1999, Catovsky & Bazzaz 2000, Haskins & Gehring 2005, Weber *et al.* 2005). Overall, the diversity of ECM and the abundance of AM fungi in southwestern Nova Scotian forests are very likely to change due to eastern hemlock loss and may even increase due to the changing forest composition.

The loss of old-growth forest may also alter mycorrhizal diversity in southwestern Nova Scotia; however, this change is likely to decrease ECM diversity. It has been well established that old-growth forests can support a higher diversity of ECM, either because they accumulate fungal species over time, or because they attract mycorrhizal fungi which have adapted specifically to associate with older trees (Birch *et al.* 2023). A study by Kranabetter *et al.* (2018) found up to 238 ECM species in old-growth Douglas fir stands in British Columbia. Additionally, Kranabetter *et al.* (2005) determined that the ECM diversity of old-growth western hemlock stands was almost twice that of their younger counterparts. Canopy closure of maturing forests has also been associated with greater ECM species diversity (Dighton *et al.* 1986) and increased mushroom production (Wallander *et al.* 2010), perhaps because the shady canopies help to retain moisture on the forest floor. Twieg *et al.* (2007) suggest that the greatest increase in mycorrhizal diversity occurs between the ages of 5 and 26 years in mixed forest, which also coincides with canopy closure for many tree species. This not only implies that the loss of old-growth trees will significantly reduce mycorrhizal diversity, but also that the regenerating forest will not achieve canopy cover, and thus a more diverse mycorrhizal community, for decades afterward. This could include the loss of important ECM fruiting bodies such as truffles (Stephens *et al.* 2017) which support insect and small mammal food webs (Shaw 1992, Luoma *et al.* 2003). In summary, the loss of old-growth trees may cause a significant reduction of ECM diversity in southwestern Nova Scotian forests which would affect these ecosystems for years to come, if not permanently.

Stress to eastern hemlock caused by HWA infestation is another major factor which may affect mycorrhizal diversity in Nova Scotian forests. Many studies have noted that mycorrhizal diversity is altered by defoliation of host trees (Lewis *et al.* 2008, Baird *et al.* 2014), and insect-stress in eastern hemlock has been associated with reduced ECM abundance and diversity when compared with healthy stands (Baird *et al.* 2014, Caruso *et al.* 2021). In fact, one study found that mushroom production decreased by a third in defoliated conifer stands (Kuikka *et al.* 2003), while Schaeffer *et al.* (2017) observed a 14% decrease in mycorrhizal colonization of fine hemlock roots after only four years of HWA infestation. These results may occur because stressed trees with defoliated canopies may be unable to photosynthesize at the same rate as healthy trees. This would reduce the amount of sugar that mycorrhizal partners receive by either directly limiting their supply or by reducing the number of fine tree roots which they use to interface with a host (Lewis *et al.* 2008). Mycorrhizal fungi can be very demanding, sometimes taking up to 25% of a tree's photosynthetic sugars (Hobbie 2006, Nehls 2008), and would be impacted negatively by a stressed or dying host tree. Interestingly, recent research suggests that host trees can actively redirect the flow of sugars to mycorrhizal partners which are less demanding (Druebert *et al.* 2009, Egli 2011). This implies that mycorrhizae which require greater amounts of sugar from their host may disappear first when their supply is cut off. However, it should be noted that some ECM are less host specific and can associate with several different tree species (Horton & Bruns 2001, Izzo *et al.* 2005). Some ECM genera, such as *Russula*, may even be able to survive without a host plant by reverting to a saprotrophic lifestyle (Štursová *et al.* 2014). Because of these advantages, these species of ECM, as well as generalist AM, would likely persist despite eastern hemlock decline due to HWA infestation. This may help explain why one recent experimental study conducted in Rhode Island, USA, did not detect any significant differences in fungal diversity between healthy and infested hemlock stands (Schaeffer *et al.* 2017).

Changes in environmental variables caused by pollution and by the loss of eastern hemlock may provoke changes in fungal abundance and diversity which can significantly influence mycorrhizal dynamics. Human activities over the past century, such as the use of combustion engines and excessive fertilization in agriculture, have increased levels of nitrogen, ammonium, and carbon dioxide in the atmosphere. Although increased growth has been observed in certain fungi of the *Paxillus*, *Lactarius*, *Thelephora*, and *Cortinarius* genera (Egli 2011), excessive nitrogen and ammonium have been shown to decrease the growth, diversity, and mushroom production of most ECM in forest ecosystems (Arnebrant 1994, Nilsson & Wallander 2003). In fact, it has been suggested that a decline in European ECM in the 1980s was caused by increased nitrogen in the air and soil (Arnolds 1991, Rühling & Tyler 1991). Contrarily, heightened carbon dioxide levels increased mycorrhizal colonization of several conifer species in a study by Godbold *et al.* (1997), demonstrating that changes in atmospheric composition can have diverse effects on fungal communities. Aside from this, the loss of old-growth eastern hemlock and their shady canopies may alter the mushroom abundance in southwestern Nova Scotian forests by increasing light levels and temperature on the forest floor. Increasing photoperiod can positively affect mushroom production by increasing the photosynthetic capacity of the host tree (Fortin *et al.* 2008). However, mushroom production is highly dependent on water availability (Egli 2011), so reduced soil moisture caused by the increase in temperature may significantly reduce mushroom abundance. This effect may be further exacerbated by the warming effects of climate change (Garbary & Hill 2021). Finally, altered soil chemistry caused by the replacement of eastern hemlock with other plant species may also change mycorrhizal composition. Eastern hemlock stands create uniquely acidic soils which are rich in organic material (Mladenoff 1987, Finzi *et al.* 1998a, b, Fassler *et al.* 2019). The loss of eastern hemlock and its shady canopies may alter cation cycling (Finzi *et al.* 1998b), reduce acidity, and increase rates of decomposition and nutrient cycling in the soil by increasing temperature and reducing soil moisture content (Jenkins *et al.* 1999, Cobb *et al.* 2006). Since different mycorrhizal fungi tend to prefer specific soil chemistries (Frelich *et al.* 1993, Finzi *et al.* 1998 a, b), changing these conditions is likely to alter which mycorrhizal species can thrive in the new forest. In total, while the overall direction of these changes may be difficult to predict, mycorrhizal diversity and mushroom production in southwestern Nova Scotian forests will likely be altered by the loss of eastern hemlock.

New research is helping to illuminate the complex relationships between fungi and their forest ecosystems (Egli 2011, Sapsford *et al.* 2017). In this discussion, we have used available literature to predict the consequences of several influential factors – changing forest composition, loss of old-growth trees, increased insect stresses on trees, and altered environmental variables – on the mycorrhizal communities of southwestern Nova Scotian forests following HWA-caused eastern hemlock decline. Replacement of eastern hemlock stands with mixed forest may increase mycorrhizal diversity and AM abundance despite the loss of hemlock-associated ECM, as more varied forests can support more diverse fungal communities (Cavard *et al.* 2011). However, loss of old-growth eastern hemlock will likely reduce ECM diversity significantly for the long-term and may particularly affect fungi preferring to associate with older trees (Birch *et al.* 2023). Further, stress induced by HWA feeding on eastern hemlocks will restrict mycorrhizal access to photosynthetic sugars from the host tree, likely reducing the diversity and abundance of ECM in hemlock stands (Lewis *et al.* 2008, Birch *et al.* 2023), but also giving an advantage to adaptable generalist mycorrhizae. Finally, increased nitrogen and ammonia levels and reduced water access in forest ecosystems may reduce diversity and mushroom production of ECM (Egli 2011), but increased light and carbon dioxide levels may have the opposite effect (Godbold *et al.* 1997, Fortin *et al.* 2008). Given this evidence, the profound changes in forest composition, stand age, tree stress levels, and environmental conditions – all significant influences on fungal diversity (Kranabetter & Kroeger 2001, Rineau *et al.* 2010, Spake *et al.* 2016) – will likely reshape mycorrhizal communities in southwestern Nova Scotian forests as old-growth eastern hemlock declines due to HWA infestations. Current research suggests that the mycorrhizal community will shift in favour of AM and generalist ECM species since these fungi may adapt more easily to a rapidly changing forest. The overall effects of the discussed factors may even indicate a potential reduction in ECM diversity; however, fungal taxonomy and the relationships between mycorrhizae and their ecosystems are not yet fully understood (Birch *et al.* 2023) – because of this, the direction of mycorrhizal changes cannot be confidently predicted at this time. Indeed, more large-scale and long-term studies are needed to truly gauge the full scope of mycorrhizal community dynamics in a changing environment (Orrego 2018).

## SIGNIFICANCE

Mycorrhizal fungi provide critical services for forest health, so changes in the mycorrhizal community may have profound implications for forest ecosystems in southwestern Nova Scotia. In exchange for photosynthetic sugars, mycorrhizae increase the access of their host plant to important resources such as water (Smith & Read 1997), nitrogen (Clemmensen *et al.* 2015) potassium (Dominguez-Nuñez *et al.* 2016), and phosphorus (Wallander *et al.* 1997) by breaking down organic and inorganic materials in the environment (Van Breemen *et al.* 1997, Hobbie *et al.* 1999, Landeweert *et al.* 2001,Wallander *et al.* 2001). They may also play a role in protecting host roots from harmful heavy metals in the soil (Adriaensen *et al.* 2004). While tree diversity is an important influence on mycorrhizal composition, mycorrhizal diversity can inversely influence forest community composition by promoting the growth of their preferred tree species (Booth 2004, Nara 2005). Furthermore, mycorrhizae may help to establish the next generation of their host tree species by transferring resources from the mature trees to their seedlings through common mycorrhizal networks (Orrego 2018), though it should be noted that this theory is contested in the scientific community and may not be sufficiently supported by evidence (Karst *et al.* 2023). Regardless, in these ways, forests and their mycorrhizal fungi are inextricably interdependent; changes in one partner may initiate a cascade of consequences that would affect the entire ecosystem, including forest regeneration. In the context of southwestern Nova Scotian forests, the decline of eastern hemlock due to HWA infestation and the subsequent changes in mycorrhizal diversity will likely result in the loss of rare hemlock-associated fungi such as stipitate hydnum species (Baird *et al.* 2013) and truffles (Stephens *et al.* 2017). This may also reduce the ability of the hemlock forests to establish new seedlings by limiting availability of compatible ECM and altering soil chemistry (Haskins & Gehring 2005). Soils which lose mycorrhizae have also been shown to lose the soil bacteria associated with those fungi (Hol *et al.* 2014), which would further alter nutrient availability and the suitability of the soil for hemlocks (Vendettuoli *et al.* 2015). Additionally, fungi are important food sources for small mammals such as flying squirrels, voles, and chipmunks (Luoma *et al.* 2003), and soil-dwelling organisms such as mites, collembola, and many insects (Newell 1984, Moore *et al.* 1988, Shaw 1992, Hedĕnec *et al*. 2013), so altering mycorrhizal diversity may have consequences for the larger food web. All this evidence suggests that the HWA disturbance will irreparably alter both the mycorrhizal and forest communities of southwestern Nova Scotia, unless immediate action is taken to protect old-growth eastern hemlock forests and their unique associated ecosystems.

## CONCLUSIONS

The old-growth eastern hemlock ecosystems of southwestern Nova Scotia are expected to experience major disturbances in the coming years due to the recent arrival of invasive HWA. Based on literature regarding the influence of forest composition, tree age, insect-induced tree stress, and environmental variables on mycorrhizal fungi, we expect the diversity of mycorrhizae in southwestern Nova Scotian Wabanaki forest to change significantly with the loss of old-growth eastern hemlock. We also predict that the mycorrhizal community composition will shift toward more generalist ECM fungi and more AM fungi as mixed forest replaces previously hemlock-dominated stands. The profound consequences of these changes will permanently alter the forest ecosystems of southwestern Nova Scotia unless immediate action is taken to conserve old-growth eastern hemlock ecosystems.

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Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 143-145

# BOOK REVIEW

***The Secret World of Lichens: A Young Naturalist's Guide.* Troy McMullin. 2022. Firefly Books, Buffalo, New York, USA, and Richmond Hill, Ontario, Canada. Pp 48, over 50 colour photographs and illustrations, 20 x 20 cm. ISBN 13:978-0=2281-0398-1, Soft-bound.**

In the beginning, all children are naturally curious and open to learning about the many living organisms that make up our world. Common wisdom among grown-up naturalists is that extensive time in the great outdoors is the key to nurturing that particular facet of curiosity and allowing it to survive to adulthood, resulting in adults who notice details of the natural world. Time outdoors is certainly important, but I think books can play a critical role in firing the imagination at any age, teaching us to notice and think about things we may otherwise overlook as simple background colour.

This the first work of non-fiction for kids dealing with North American lichens. Like most non-fiction written for children and young adults it introduces the topic in a general way with a selection of fun facts and illustrated examples. The reader should not expect a field guide or exhaustive reference book. The writing is most appropriate for older elementary school children with strong reading skills or teens, however the images and some of the content could be of interest to younger children or even adults. The size and length are similar to other non-fiction picture books with a shorter spine than average, resulting in pages large enough to accommodate larger photographs than a field guide but small enough to fit neatly on most book shelves. The price is reasonable and will be affordable for many families and libraries.

The first section of the book provides an introduction to lichens broken into small manageable sections which are sensibly organized. This is the most text-heavy portion of the book but the liberal use of photographs and illustrations provides at least one focal point on every page that should help to catch and keep the reader's attention. The author introduces the concept that there are lichens right under our noses and defines what a lichen is, succinctly explaining its symbiotic and photosynthetic lifestyle. Then he introduces the basic growth forms followed by the most essential details of the structures of a lichen. From there he moves on to lichen evolution, growth rates, ecology and human uses. Finally, he gives advice on finding and documenting lichens. Overall the content of the introduction is thoughtfully chosen, providing a solid grounding in lichen basics and a number of interesting facts about things like lichen-patterned camouflage for caterpillars and lichen-based dyes or medicines.

The main portion of the book presents a brief account of 38 lichens with most species getting a whole page to themselves. The species selected range from Arctic to tropical species and cover every major growth form. Only the best travelled young naturalists will be able to see all 38 species in person, but readers from every region of Canada will have a chance to find something from this book in their area. Each page is headed by the lichen name (common name listed first, then scientific name) followed by a brief block of text including a general description, notes on habitat and geographic range and sometimes an additional interesting fact about the lichen included in the main text or in a discrete fact box. A high-quality photograph dominates each page (sometimes with an additional inset photo of the underside) with beautiful results.

Throughout the book the text is simplified to avoid lengthy explanations and excessive jargon while attempting to maintain scientific accuracy. For the most part the author strikes a good balance here. Most scientific terms are presented in bold when first introduced and are defined in a glossary at the end of the book. This glossary could benefit from expansion to include some words that are likely unfamiliar to the target audience. For example, the terms "vegetative" and "sexual" appear in the introductory section on "Lichen Reproduction and Structure" as possible modes of reproduction and should ideally have been defined. Two lichen specific terms for vegetative reproductive structures—"soredia" and "isidia"—are also omitted from the glossary, which is unusual but reasonable since they are clearly defined on the only page in which they are mentioned.

Most of the details omitted for simplicity's sake will not cause any confusion for young naturalists who decide to move on to more detailed lichen books. That said, the use of terminology relating to growth forms does deviate a little from that used in other works on lichens (e.g. Brodo et al. 2001; Hinds and Hinds 2007). Lichens composed of groups of small, discrete shingle-like or scale-like growths are often called "squamulose"; McMullin chose to omit this term, referring to such forms as small “foliose” growths instead (e.g. *Cladonia chlorophaea* on p. 33). The term “fruticose” refers to three-dimensional stalked, bushy or thread-like growth forms without a clear upper and lower surface; most authors use this term in reference to the main lichen body (containing fungi and algae or cyanobacteria) while McMullin expands its use to some tall fruiting bodies composed of fungal tissue alone (*Calicium trabinellum* on p. 46, *Chaenotheca obscura* on p. 38 and *Lichenomphalia umbellifera* on p. 29). These choices make for easier reading but will require an adjustment in thinking for any reader who goes on to a serious study of lichens.

Apart from the stunning photography, my favourite thing about this book is the way the author frames learning to spot lichens as an invitation to a “Secret World”. Robin Wall Kimmerer (2003) wrote eloquently about her and her students’ experiences “learning to see”, drawing attention to the phenomenon of failing to notice organisms for which we lack a search image and the powerful interplay of words and perception. Although Kimmerer was writing mainly about bryophytes, McMullin’s aptly named book touches on the same themes. The way he talks about looking for lichens would resonate with most people who have fallen in love with the study of lichens or other small things. In the very first page, he encourages the reader to “look closely” at the substrates around them to discover a “secret world full of bright colours and interesting shapes that resembles a coral reef”. On the last page of the introduction he talks about knowing that this secret world has been revealed when you start seeing lichens everywhere.

Overall, this is a beautiful and informative book that will teach young readers to see and appreciate lichens, revealing their “Secret World” by providing the tools to make sense of the colours and textures that lichens form out in nature. I look forward to sharing it with my own children.

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Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 147-150

# BOOK REVIEW

**_Endless Novelties of Extraordinary Interest. The Voyage of H.M.S._ Challenger _and the Birth of Modern Oceanography._ Doug Macdougall. 2019. Yale University Press, New Haven, London, 257 pp.**

One hundred and fifty years ago, on May 9, 1873, the Royal Navy's corvette H.M.S. *Challenger* steamed into Halifax harbour to begin a ten-day stay for repairs and reprovisioning. Under normal circumstances this would not have been an unusual event – Halifax was, after all, the Royal Navy's pre-eminent base in the western North Atlantic. The comings and goings of R.N. vessels were regular events. But *Challenger* aroused particular interest because of its goals, which were not naval but scientific. While in port it entertained a procession of Halifax citizenry, particularly members of the Nova Scotian Institute of Science, and its personnel went ashore for rest, relaxation, and the pursuit of natural history in a new environment.

The background of *Challenger*'s cruise – which took 3-1/2 years and covered 68,890 nautical miles - lay in an expanding interest during the 1860s and '70s in the nature of life and the physical conditions under which it existed in the deep ocean. With the support of the Royal Society and the Royal Navy (particularly of its hydrographer George Richards) two natural scientists brought their plans for a major investigation of the oceans to fruition. The first was Charles Wyville Thomson, then Regius Professor of Natural History in the University of Edinburgh, and W.B. Carpenter, physiologist at the University of London and a vice-president of the Royal Society. They had been collaborating through the 1860s on biological collecting in deeper and deeper water around the British Isles and now saw the opportunity to investigate the organisms and physico-chemical conditions of the deep sea on a global scale. In a remarkably short time a major expedition was put together, no small part of which was re-purposing, renovating and provisioning a superannuated warship, H.M.S. *Challenger*, for scientific work.

Doug Macdougall's interesting, attractively-written book on the expedition is a recent addition to oft-told tales in a new context. Shortly after the return of *Challenger* to England in 1876, some of the participants prepared their accounts of experiences on the expedition, notably Sub-lieutenant Lord George Campbell's *Log-Letters from "The Challenger"* (1876) and H.N. Moseley's *Notes by a Naturalist on the "Challenger"* (1879). Other participants from among the naval staff of the ship and the group of six scientists aboard eventually did the same, giving views of science at sea and on land plus people and places around the world. The centenary in 1972 of the departure of *Challenger* from England evoked a new outpouring of popular and more academic historical treatises, making the famous cruise extremely well documented, at least from the point of view of the serving officers and the scientists (a series of colour sketches by a cooper, Benjamin Shephard, was discovered in 1968, and there is an account by a steward's assistant, Joseph Matkin, discovered and published in the 1990s, giving views from below decks - we could do with more if they exist). Macdougall relies extensively on Campbell and Moseley for vivid commentary on work at sea and explorations on land – with justification, because Campbell's witty insouciance (as befitted a son of the Duke of Argyll) did not disguise his keen eye for the ridiculous and the interesting, and Moseley was among the most enquiring of the scientists ("naturalists") aboard (his studies ranged from animal functional morphology and behaviour to linguistics and physical anthropology).

Macdougall does not commit the sin of Whig historiography – seeing current knowledge as the result of a logical progress from a more primitive past to an enlightened present - but he does use modern scientific knowledge of the oceans and their inhabitants to provide context for the frequently surprising observations and discoveries made by the *Challenger* scientists. This approach works well, at least to my eyes. Without overburdening the reader with everything that happened on board, he selects several examples of scientific observations or discoveries that were novel in their time, sometimes inexplicable with 19$^{th}$ century knowledge of biology, physics or chemistry, but that presented themselves to a dedicated team of observers with virtually unlimited time and resources on the first great scientific exploration of the oceans. It is hard not to be caught up in debates over the origin of oceanic sediments, the search for the origins of life, beginning the untangling of coral biology, the thrill and extreme danger of being alone - really alone - in the iceberg-filled Southern Ocean, or the difficulty and danger of trying to find birds of paradise in Australia and New Guinea. The examples are varied, vivid and engagingly presented.

One of *Challenger*'s scientists, the chemist J.Y. Buchanan, claimed in later years that the science of oceanography began with the ship's first official deep-sea station, made west of the Canary Islands on February 15, 1873. Similar views are found in later years, into our own times, particularly in the prefaces to oceanography texts, in which *Challenger* is invoked as the originator of a new science. The case could be made too that the 50 volumes of the *Challenger* Reports, published between 1880 and 1895, mainly due to the immense energy of the *Challenger* naturalist John Murray, formed the basis of modern oceanography. Others are more sceptical (I have been among them), pointing out that that in many respects the *Challenger* Expedition was the culmination of an older tradition, using outdated techniques and approaching scientific problems in a way that was the epitome of 19th century European science. I now view this as a pointless debate – *Challenger* was what it was, not a precursor nor a last gasp of an old tradition.

Macdougall concludes his book, in a chapter titled "*Challenger*'s Enduring Legacy" with a measured assessment of the significance of the great expedition, particularly focussing on the reports and John Murray. Many factors of 19th century science

> "…converged to ensure that the *Challenger* project was supported by the government as a standalone enterprise. The expedition and the later work it spawned, especially in the Challenger Office in Edinburgh, fostered a new, more collaborative way of doing science. The participants were loosely organized and independent, but supported by public funds. This was a mode of working that enabled them to accomplish more than had been possible previously, and it ushered in an era in which similar organizational structures sprang up elsewhere" (p. 236)

And as he goes on to say,

> "By the time the last volume of the report was published, in 1895, and the Challenger Office closed [it was in Edinburgh, partly housed in Murray's residence in Granton], a small informal but influential worldwide community of marine scientists had come into being. To a considerable extent it owed its existence to the expedition. A few years later, in 1899, the king of Sweden invited many of these marine scientists from around the world to Stockholm to attend the first International Conference on the Exploration of the Sea.

> John Murray, who had recently been knighted by Queen Victoria, headed the British delegation. The conference was a signal that oceanography was by now firmly established as a discipline in its own right." (p. 240)

Macdougall quotes Murray on the significance of the *Challenger* Expedition: as "the greatest advance in the knowledge of our planet since the celebrated discoveries of the fifteenth and sixteenth century." (p. 241). Perhaps true, but perhaps of more importance was how it was conducted and how its results were produced and disseminated for, quoting Macdougall, "the *Challenger* expedition and its research and publication program indisputably served as a model for a new kind of marine research" (p. 240) – one that involved large (and expensive) enterprises in which governments played a part, research was done and shared collaboratively, and with international collaboration if not in the doing, certainly in its spread. In my opinion, McDougall gets it just right when he concludes that "*Challenger*'s moment in the sun was a turning point in the long history of humankind's fascination with the sea." (p. 241). This book is a very useful, well thought-out, and attractive presentation of *Challenger* science, but equally of what made it significant in the long run for marine science from the late 19th century into our own times.

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Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 151

# OTHER RECENT SCIENCE BOOKS OF NOTE

***The Rise and Fall of the Dinosaurs: A New History of a Lost World.*** **Brusatte, Steve. 2018. William Morrow, Harper Collins, New York. 416 p.**

Senior readers will remember learning that many dinosaurs had small brains and were large slow-moving animals, superseded by mammals and birds. However, this fascinating history reveals that this is all wrong and that birds are dinosaurs; their flightless ancestors being covered with feathers, and they had wing-like structures for display, like peacocks. In addition, this history provides accounts of many of the early and more recent paleontologists who have collected evidence to support our current understanding about the evolution of these remarkable animals.

***The Violinist's Thumb and Other Lost Tales of Love, War, and Genius, as Written by our Genetic Code*****. Kean, Sam. 2013. Little Brown & Co. Boston. 432 p.**

This book that is all about DNA and human hereditary and evolution. At first glance, one might think that the topic is too complex for a general readership and in parts there is a lot of detail, but there are helpful explanatory end-notes on each chapter. The book is packed with enthralling information about the scientists, and others, associated with the various discoveries. It is also fascinating to read about the genetic mutations that have affected famous people like American Presidents and others like Paganini whose aberration led to the book's title. Once into the book, it is not easy to put down and it provides a great insight into understanding the role DNA, RNA, and the genetic code in human populations today.

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Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 153-156

# NSIS EXCURSIONS 2023

HANK M.B. BIRD*
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Annual excursions for members of the NSIS are a key component of the Institute's program. They take place in the spring, summer and fall months, and include visits to museums, historic sites, parks and other points of scientific interest in the Province. We are always looking for ideas and leaders for such trips. We had two excursions this year, described here.

## URBAN GEOLOGY – EXPLORING THE HALIFAX CITADEL

In April, we had a pop-up excursion co-sponsored with the NS Museum of Natural History. Tim Fedak of the Museum and the NSIS led a group of about 20 people on a 2 km urban geology walk on the Halifax Citadel drumlin. It was a pleasant and educational outing. We learned quite a lot about the geological aspects of this feature which sits right in the centre of our city as part of the Halifax Citadel National Historic Site.

The tour included historical references to the Halifax Explosion (1917), a British Survey monument (c. 1817), and information about the glacial drumlin that was deposited and shaped by glaciers 20,000 years ago. Participants were encouraged to visualize 1-2 km of ice above the ground during the glacial period 80,000 to 15,000 years

**Fig 1 Our guide giving explanations of the Citadel's geology.**

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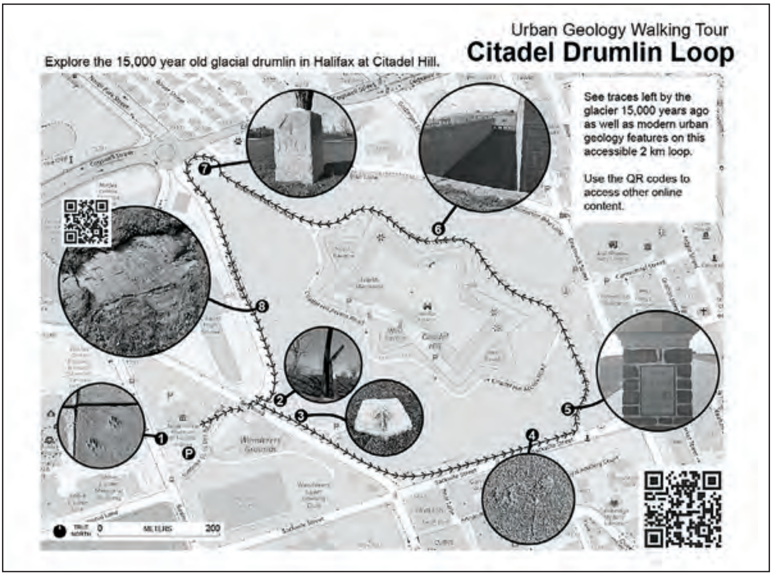



**Fig 2 Route map of the Citadel Drumlin Urban Geology Walking Tour (Pers. comm. Fedak 2023).**

ago. The excursion also included looking at the glacial striations at the base of the Citadel drumlin in the field across from Citadel High School (Figs 1-2).

## KEJIMKUJIK NATIONAL PARK AND NATIONAL HISTORIC SITE

In early July, nine of us went to Kejimkujik National Park and National Historic Site for a guided outing that included learning about the petroglyphs of Kejimkujik (Keji) Lake and having a nature hike in the woods near Grafton Lake.

We had an enthusiastic interpretation of the petroglyphs in the morning, by a knowledgeable Parks Canada employee. This took place in front of the historic site monument, Mi'kmac Cultural Landscape at Kejimkujik, (see front cover of this Issue), and at a talking circle close to Keji Lake. Although on this trip we could not see the petroglyphs on the lake rocks due to the unusually high water level, we were able to view a range of carefully made impressions of them, rock carvings that date back hundreds of years.

In the afternoon, we embarked on a nature walk with a park naturalist. This walk focused on some of the unusual botanical features in the Park, especially fungi and lichens present in the forest undergrowth. In between the two events, we had a nice picnic lunch beside Keji Lake, and learned a lot about indigenous canoe-making from the long-time resident expert. It was a perfect weather day and we enjoyed Kejimkujik park at its best. Stay tuned for another visit in 2024 (Figs 3-6)!

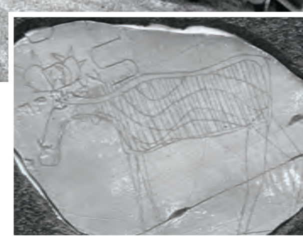


**Fig 3** **A talking circle, listening to the story behind the petroglyphs of Kejimkujik Lake.**

**Fig 4** **An impression of one of the petroglyphs found on the rocks along the lake. This is a protected site.**


**Fig 5** **The birch bark canoe display, with master builder, Todd Labrador, in the foreground.**

**Fig 6 Listening to the naturalist describe features of the mixed growth forest near Grafton Lake.**

Proceedings of the Nova Scotian Institute of Science (2023)
Volume 53, Part 1, pp. 157-172

# NSIS COUNCIL REPORTS

## Reports from the Annual General Meeting
## May 29, 2023 - 5:45 pm

## AGENDA

## 162nd ANNUAL GENERAL MEETING

*Meeting held in McNally Auditorium,*
*Saint Mary's University and via Zoom.com*

1. Minutes of the 161st AGM, 3 May 2021
2. Vote to accept Minutes of the 161st AGM
3. President's Annual Report (Stephanie MacQuarrie)
4. Treasurer's Annual Report (Angelica Silva)
5. Editor's Annual Report (Peter Wells)
6. Librarian's Annual Report (Stephanie MacQuarrie for M. Paon)
7. Membership Annual Report (Stephanie MacQuarrie for S. McInnis)
8. Webmanager's Annual Report (Romman Muntzar)
9. Publicity Annual Report (Brent Robicheau)
10. Excursions Annual Report (Hank Bird)
11. Vote to accept the 8 Reports
12. Student Science Communication Competition for 2023 (Jillian Phillips)
13. Lecture Programme for 2023-2024 (Anne Dalziel)
14. Revisions to the By-Laws (Stephanie MacQuarrie)
15. Vote to accept the New By-Laws
16. Nomination of 2023-2024 Council (Stephanie MacQuarrie)
17. Vote to approve the new Council
18. Any Other Business
19. Adjournment

**Note:** Following the AGM, at 7:30 pm there was a Public Lecture in the Auditorium and via a separate Zoom Call. Dr. Jantina Toxopeus (St. Francis Xavier University) presented "Winter: A Bug's-Eye View. How Animals Survive the Winter".

*Dr. Tamara Franz-Odendaal*
*NSIS President*

## MINUTES OF THE 162ND NSIS ANNUAL GENERAL MEETING

**Council Members & Observers Present:** Stephanie MacQuarrie (President), Anne Dalziel (Vice-President), Tamara Franz-Odendaal (Past President), Angelica Silva (Treasurer), Peter Wells (Editor), Michelle Paon (Librarian), Brent Robicheau (Publicity Officer), Hank Bird (Secretary and Excursions), Jinshan Xu (Councillor and SSTCC), Jillian Phillips (Observer, Discovery Centre Observer and SSTCC), Chenille Callendar (Discovery Centre Observer), Carol Morrison (Observer), Ale Torres (MSVU Student Representative), David Richardson (Associate Editor).

**Members Present:** Patrick Ryall, Sheila Crain, Sherry Niven, Paivi Torkelli, Andrew French, Jeff Turner, John Young, Barbara Zielinski, Jantina Toxopeus,

**Regrets & Absent (Council Members & Observers):** Shea McInnis (Membership Officer), Romman Muntzar (Webmanager), Nicoletta Farone (Councillor), Youyu Lu (Councillor and STCC), Tim Fedak (Nova Scotia Museum Observer), Alina Pindar (Observer), Ali Shafiee (Observer).

**Welcome:** The President welcomed members and called the 162nd Annual General Meeting (AGM) to order. The President noted that presentations would be kept short and informal and that the reports, excluding the minutes from last year's AGM, would be approved as a unit at the end of the presentations.

1. **Approval of the Minutes of the 161st Annual General Meeting of 2 May 2022:**
   There were no revisions to those Minutes.

2. **Motion to accept the minutes of the 161st AGM:**
   Moved: A. Dalziel
   Seconded: A. Torres
   All in favour: Approved unanimously.

3. **President's Annual Report (Stephanie MacQuarrie):**
   S. MacQuarrie thanked the Council for its hard work and its support during her first year as President, with special thanks to:

   - A. Dalziel for her VP support and for organizing the Public Lectures series.

- T. Franz-Odendaal and R. Muntzar for managing the revamping of the NSIS website.
- B. Robicheau for promoting the NSIS online via social media.
- J. Phillips, Y. Lu, and J. Xu for co-coordinating the Student Science and Technology Communications Competition (SSTCC).
- H. Bird for his support at Secretary.

The President noted that our new website has been designed and is up and running with a new service provider. It has new features and content, and it is easier to navigate. She noted that we welcome suggestions for content, appearance and improvements.

She also noted that we plan to start a short periodic NSIS Newsletter in the fall of this year. The newsletter needs a name, and we may run a competition to select one.

Our Librarian, Michelle Paon, has retired after many years of outstanding service to the NSIS. We are still working on a replacement. The NSIS By-laws have required that our Librarian must be a Science Librarian at Dalhousie University, but the Dalhousie Killam Library currently has staffing limitations. We propose to change the By-Laws to allow our Librarian to be any Librarian with access to the collections at the Killam Library (see item #14).

This year we were active in our Strategic Planning and have several actions that will carry into the 2023-2024 year. Among them are:

- Increasing the number of members.
- Encouraging corporate partnerships and financial support.
- Starting a periodic NSIS Newsletter. It will need a name, and we may run a competition to select one.
- Starting an Awards Committee to recognize (1) significant work by Nova Scotian scientists, and (2) significant contributions to the work of the NSIS.
- Obtaining “swag” or NSIS-identified items such as t-shirts, coffee mugs, pens, etc. that can be sold (or given as tokens).

The following Public Lectures (hybrid: in-person and Zoom) took place over the 2022-2023 NSIS year:

- **Oct. 3rd, 2022: "How the Black Soldier Fly Can Help Turn the Global Protein Crisis Around".**
  Dr. Greg Wanger (Oberland Agriscience).
- **Nov. 2nd, 2022: "Drawing on Science: Mastodons of Nova Scotia".**
  Dr. Tim Fedak (NS Museum of Natural History).
- **Dec. 6th, 2022: "New Lessons from Old Mountains: What Are Our Rocks Trying to Tell Us?".**
  Dr. Deanne van Rooyen (Acadia University).
- **Jan. 9th, 2023: "Getting Nova Scotia Off Oil, Off Coal, and Off Gas".**
  Dr. Kathlyne Nelson (NS Dept. of Natural Resources)
- **Feb. 6th, 2023: "Student Symposium: Climate Science in Nova Scotia".**
  Several student scientists (from nearby NS research institutions).
- **March 6th, 2023: "Accelerating Natural Ocean $CO_2$ Sequestration as a Climate Change Solution?"**
  Dr. William Burt (Planetary Technologies). POSTPONED to 2023-2024 year due to scheduling conflicts.
- **Apr. 3rd, 2023: "How to Stop Global Warming".**
  Dr. Andrew MacDougall (St. Francis Xavier University).
- **May 29th, 2023: "Winter: A Bug's-Eye View; How Animals Survive the Winter".**
  Dr. Jantina Toxopeus (St. Francis Xavier University).

The President called on members of Council to present their reports.

**4. Treasurer's Annual Report (Angelica Silva):**
As of March 31st, 2023, the net worth of the NSIS was $32,902.38, held in our BMO bank account. Of this, $17,902.38 is in cash, and $15,000.00 is in an 18-month GIC paying 4.15% per year.

Revenue from all sources were $4,543.73 ($3,023.01 as individual memberships). Other revenue was $150.00 in Institutional Memberships and $370.72 in Income/Access Copyright Royalties. There was also a contribution of $1,000.00 from the NS Bird Society, to be applied to a reprinting of *The Birds of Brier Island*.

Expenditures amounted to $6,340.95 (including $4,535.08 of for production of the *ProcNSIS*). Other expenditures included $907.45 for the *ProcNSIS* mail-out, $41.86 for Publicity and Advertising, $644.10 partial payment for our new website design, and $212.46 for the website domain. (NOTE: in a normal year we would also contribute $1,000.00 to support school Science Fairs in the province, but there were none in 2022 due to Covid. Also, we would normally spend $1,500.00 on SSTCC prizes, but the competition was not completed in 2022.)

The Treasurer noted that, as of May 2nd, 2022, the NSIS currently has a total of 127 active members and 10 institutional members. (See item #7.)

We thank Carol Richardson (Dalhousie Killam Library) for her continuing contribution with NSIS mail at Dalhousie University, and for library services. Many thanks to graduate student Shea McInnis (SMU) for his contribution as a Membership officer and to Romman Muntzar for compiling and transference of membership payments. Many thanks to NSIS Secretary Hank Bird for multiple roles and contributions with mail and banking.

D. Richardson suggested that we stop using PayPal as a payment method and move to direct bank transfers. A. Silva and H. Bird reported that they have begun to look into making this change.

Finally, the Treasurer noted the passing in March of Elaine McCullough, who served the NSIS as an outstanding Treasurer for many years. D. Richardson noted her service to Saint Mary's University Retirees in the same capacity.

**5. Editor's Annual Report (Peter Wells):**

The PNSIS continues successfully, thanks to the hard work of the Editorial Board and the widening interest across Nova Scotia and the Maritimes in contributing relevant papers to our regional, peer-reviewed science journal.

The latest issue, PNSIS Vol. 52, Part Two, published in October 2022, is on the NSIS website. As with all previous issues, it is open access for readers. Printed copies were sent out to NSIS members upon request, as well as to exchange libraries and institutes. The print run of 150 copies is now exhausted.

Contributions for PNSIS Vol. 53, Part One, 2023, are still being sought, with a deadline of June 30th and completion date of late summer. To date, we have three confirmed Commentaries, two Research papers (one in review), two student submissions, and two Book Reviews. We will include the AGM Minutes, the program of talks and other activities planned for 2023-24, and an Editorial.

During the winter, the Editorial Board was reminded to actively solicit research contributions, commentaries and book reviews from their colleagues and students. The Institute's members can also help to spread the word about NSIS and its journal through social media and personal contacts.

On that note, two of us attended the Fishermen and Scientists Research Society (FSRS) Annual Conference (fsrs.conference@gmail.com) on March 21st, in Dartmouth. We set up a display table with BoFEP (Bay of Fundy Ecosystem Partnership), sharing the space and cost and distributing the latest NSIS brochure, membership form, and some past Proceedings. The conference was well attended; lots of people stopped by and showed interest. It was a great way to network between our societies and help build NSIS membership!

We will participate in Ocean Day next week on the Halifax waterfront and distribute the NSIS brochure – all part of building NSIS membership and interest in the PNSIS and regional science!

**6. Librarian's Annual Report (Carol Richardson for Michelle Paon):**

The NSIS Librarian serves as a liaison between the Dalhousie University Libraries and the Nova Scotian Institute of Science. The Administrative Assistant, Carol Richardson, works with the Librarian to communicate with NSIS journal exchange partners from around the world and oversees the receipt of partner journals. They both work with Dalhousie Libraries' staff members in the Killam Memorial Library who prepare these journals for the shelves and facilitate access to the online *Proceedings of the Nova Scotian Institute of Science*.

*Proceedings of the Nova Scotian Institute of Science*

During June 2022-April 2023, there were no sales of the *Proceedings* from the Killam Library's Reference & Research Services office. The Reference & Research Services Administrative Assistant packaged and mailed 61 copies of the new issue (vol. 52, pt.2, 2022) to NSIS members (59 externally and 2 internally to Dalhousie). An invoice for $665.02 was received for charges incurred by the Dalhousie Libraries for the mailing of the Proceedings.

*Indexing and Abstracting Services*

NSIS also sent complimentary copies of the most recent issue of the *Proceedings* to the National Library of Canada (2 copies) & the Library of Congress.

*Access Copyright*

Any payments received from Access Copyright was sent directly to the NSIS treasurer.

*Institutional Members and Exchange Partners*

NSIS sent renewal invoices to its institutional partners of which 9 have renewed their subscriptions. There are currently 14 Institutional members and 81 Exchange partners.

*NSIS Exchange Journal Collection*

NSIS receives journal issues from exchange partners around the world. As an example, from June 2022 to April 2023, NSIS received 28 journal issues and society publications from the Institute's exchange partners. These items were delivered to the Dalhousie Libraries (Killam Memorial Library location), where they are processed and added to the NSIS collection in the library.

S. MacQuarrie thanked Carol Richardson and Michelle Paon for their librarian support over a large number of years. D. Richardson noted that the *ProcNSIS's* circulation to other libraries and institutions stimulates contributions of journals to the Killam Library's collections. Finally, M. Paon noted that while many institutions no longer produce print copies of their journals (they are open access only), there is value in providing limited print runs of *ProcNSIS*.

**7. Membership Annual Report (Hank Bird for Shea MacInnis):**

*Membership Overview:*

To date, there are currently 127 active members of the NSIS, plus 10 institutional members. This is slightly higher than a year ago.

| Type of Mbrshp. | AGM 2023 | AGM 2022 |
|---|---|---|
| Honorary | 2 | 2 |
| Life | | |
| 26 | 25 | |
| Regular | 76 | 74 |
| Student | 6 | 15 |
| Complimentary (Lecturers, SSTCC) | 17 | 6 |
| | 127 | 122 |
| Institutional | 10 | 11 |
| | 137 | 133 |

*Membership Drive:*

We held a Membership Drive in September-December of 2022. There were two prizes awarded – each prize was 3 signed copies of books by Soren Bondrup-Nielsen.

**8. Webmanager's Annual Report (Romman Muntzar):**

This year, the main tasks that were done were updating the NSIS website with the upcoming talks on the Public Lectures page, the Student Science and Technology Communication Competition winners results and miscellaneous edits needed occasionally for the website.

Money from the PayPal account continued to be transferred to the BMO account and the PayPal Membership update excel sheet was also updated as the money would be sent. The document is also sent to Angelica Silva and Hank Bird every month.

A whole new page on the website was set up for the AGM meeting and the PayPal account was set up to receive a fixed amount of money so that it was more convenient for people to purchase the AGM buffet dinner, as well as renew their membership for the coming year.

Lastly, the NSIS website had an ongoing server issue (for the last month and a half) that became quite hard to fix. Our web designer, Abe Omorogbe, was contacted and he fixed the issue for a nominal price. Once the website was back up, additional last-minute edits were made and pictures of the competition winners were added.

**9. Publicity Annual Report (Brent Robichaud):**

*Highlights:*

1. Early in the year the Publicity Officer generated annual promotional material for the lecture series. This included:

   i. Our annual NSIS brochure featuring the list of all seminar speakers for the year, a President's message, and addtional general information about the NSIS and how to become a member,
   ii. Lecture speaker posters for distribution each month,
   iii. Monthly lecture ads/graphics for social media posts.

   Additionally, Facebook events were generated for all forthcoming lectures. The lecture series was also advertised monthly on Twitter typically 1-2 weeks prior to the event. Other ads posted to FB and Twitter as requested (for e.g., membership drive & writing competition).

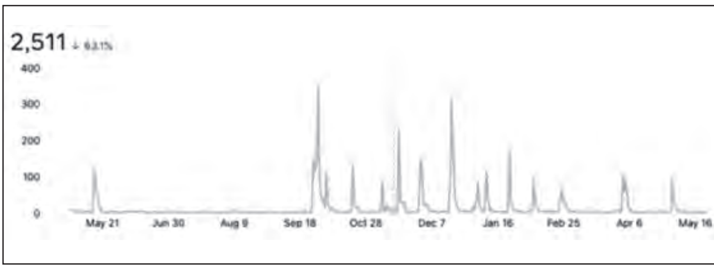
   Also, this year university science administrators were notified of upcoming lectures via email each month.
2. The Publicity Officer continued to work on refining our list of potential action points for increasing graduate student engagement. A small committee was formed (including J. Phillips and H. Bird) to work on presenting ideas to the executive that may be worth pursuing (considering things such as resources of the NSIS and potential time-commitments for each action point relative to their potential for success), and then gathering further feedback from the executive committee. This is an ongoing topic that will continue to be worked on into 2023-2024.
3. The Publicity Officer worked alongside President and VP to conduct an NSIS membership drive, including securing signed books from local author Dr. Soren Bondrup-Nielsen for prizes.

4. The Publicity Officer assisted the VP with the student symposium with respect to establishing and monitoring the abstract submission portal.

*Facebook: (past year; 1-May-2022 to 23-May-2023)*

Page Reach values are shown. (Page Reach = "the number of people who saw any content from your Page or about your Page, including posts, stories, ads, social information from people who interact with your Page and more." )

*Assessment:* In 2021/22 we had 435 page visits, this year 2022/23 we had 491 page visits, so about the same as the prior year.




*Twitter: (Note that Twitter does not provide graphics for entire year)*

*Assessment:* based on the number of followers we had 136 followers in May 2022, and in May 2023 we have 187 followers. Hence, a net gain of 51 followers this past year.

**10. Excursions Annual Report (Hank Bird):**

For the record, we did 13 excursions in 2016, 2017, 2018, and 2019. Due to Covid-19, no NSIS Excursions were conducted from the Spring of 2020 until May 2022.

In May 2022, we teamed with the Halifax Field Naturalists who provided a guided nature walk in the Purcell's Cove Backlands. It was a glorious day, and we learned a lot about the flora, fauna, and ecology of this dramatic and unique area in our midst.

In April 2023 we had a pop-up excursion co-sponsored with the NS Museum of Natural History. Tim Fedak led a group of about 20 people on an urban geology walk on the Halifax Citadel drumlin. It was a pleasant and educational outing, and we learned quite a lot about the geological aspects of this feature right in the centre of our city.

At the moment two excursions will take place later in 2023.

- We have set up an excursion at Kejimkujik National Park in July for a guided outing to include the petroglyphs and a nature hike.
- Dr. Linda Campbell of SMU has agreed to lead an outing to the Montague Gold Mines in October.

Other possibilities include:

- Waterfalls of Nova Scotia
  (various sites)
- Shubenacadie Wildlife Park
  (Shubenacadie)
- Cape Split Nature Hike (Scots Bay)
- NS Museum of Industry (New Glasgow)
- Canadian Geological Association (joint excursion)
  (TBD)

We welcome additional suggestions and possibilities.

These are the 15 excursions we had in 2016, 2017, 2018, 2019, 2022, and early 2023:

- Natural History of McNab's Island
- Annapolis Royal Historic Gardens (twice)
- The Science and Art of Making Beer,
  at the Garrison Brewery.
- Burke-Gaffney Observatory
- Joggins Fossil Cliffs
- Shubenacadie Canal
- Bedford Institute of Oceanography
- Dalhousie Planetarium
- Habits and Habitats of NS Birds
  (in association with the NS Birding Society)
- Otter Ponds Demonstration Forest
- The Science and Art of Making Beer,
  at the 2 Crows Brewing Company
- Fundy Geological Museum, Ottawa House,
  and the Tidal Power Exhibit.
- Discovery Centre (including "behind the scenes")

- Purcell's Cove Backlands (in association with Halifax Field Naturalists)
- Halifax Citadel Drumlin Geological Walk

**11. Motion to Accept the Annual Reports:**
Moved: A. Dalziel
Seconded: A. Silva
All in favour: Approved unanimously.

**12. Student Science Communications Competition for 2023 (Jillian Phillips):**
This year the competition was co-coordinated by J. Phillips, Y. Lu and J. Xu, with some support from H. Bird. The co-coordinators recommend that subsequent competitions continue to be managed by 2 or 3 persons, rather than a single individual.

This year the "essay" category was introduced across all categories, replacing the "research" paper category with the hope to make the competition more accessible to undergraduate and college students. We also dropped the requirement for a short video synopsis about a submission's topic, focussing on writing skills.

The overall goals were to:

- Promote the communication of science and technology in NS.
- Provide students an opportunity to practice their STEM communication skills and receive meaningful feedback on their writing.
- Generate interest in and submission for publication in the Proceedings of the NSIS.

*Judges:*

- Hank Bird
- Anne Dalziel
- Tim Fedak
- Youyu Lu
- Romman Muntzar
- Jinshan Xu

*Submissions:* 9 papers from 4 NS Universities and from NSCC.

- Dalhousie University (5)
- Acadia University (1)
- Cape Breton University (1)
- Mount St. Vincent University (1)
- Nova Scotia Community College (1)

*Results:*

- Undergraduate Winner: Aliya Seward (Human Nutrition, MSVU)
- Undergraduate Honorable Mention: Kiya Heneke-Flindall (Environ. Sci., Dal.)
- Postgraduate Winner: Rebecca Mader (Mycology, Acadia U.)
- Postgraduate Honorable Mention: Reid Sutherland (Marine Management, Dal.)

**13. Lecture Program for 2023-2024 (Anne Dalziel):**
Alana Pindar and Anne Dalziel propose the following 8 speakers/events for next year, based upon suggestions:

1. Dr. William Burt, Planetary Technologies. "Accelerating natural ocean CO2 sequestration as a climate change solution? Testing the safety and viability of Ocean Alkalinity Enhancement". (Hybrid, in Halifax).
2. Student Symposium. "TBA". (3 speakers, Hybrid, in Halifax; give prize for crowd favorite). This is a key student event. We will ask for feedback on the topic, especially from our student members!
3. Student Event: "Career Q&A". (4-5 speakers, hybrid, in Halifax).
4. Kathleen Aikens, Executive Director ACAP CB: "Trashformers".
5. Dr. Allison Mackie, CBU. "Treatment of industrial wastewater". (Hybrid, In Sydney).
6. Confederation of Mainland Mikmaq (speaker TBA): Ongoing research in Aquatic Resources & Fisheries Management and Environment & Natural Resources programs.

7. Dr. Paul Manning, Dalhousie Agriculture. "The importance of biodiversity (specifically insects) to the health and functioning of agricultural ecosystems".
8. Dr. Linda Campbell, SMU ENVS: "Contamination from historical goldmines in NS".

**14. Revisions to the By-Laws (Stephanie MacQuarrie)**

The Council has recommended a number of small changes to the NSIS By-laws. The vote in Council was 9 in favour plus 1 abstention. Copies were e-mailed to the NSIS members prior to this meeting. Most of the changes were cosmetic or for clarification. Highlights include:

- Updating language, e.g.: "Webmaster" to "Webmanager", "Lecture Series" to "Speaker Series", etc.
- Updating the responsibilities of the Vice-President position.
- Updating Librarian position so that it can be a Librarian with access to Killiam Library.
- Adding a Speaker Series Chair position, responsible for managing the yearly series of public lectures and events.
- Removing the requirement that membership cards be issued.
- Noting that all councillors are expected to participate and contribute..

**15. Motion to Approve the New By-laws:**

Moved: T. Franz-Odendaal
Seconded: H. Bird
All in favour: Approved unanimously.

**16. Report of the Nominating Committee for the 2019-2020 Council (S. MacQuarrie):**

The President thanked the outgoing Council and remarked that S. MacQuarrie and the Nominating Committee made efforts to increase the Council's diversity for institutions represented, disciplines, age, gender, and geographic location. The AGM was asked to elect the following to NSIS Council for 2023-2024:

*Officers:*

| | |
|---|---|
| President | Stephanie McQuarrie |
| Vice-President | Jillian Phillips |
| Past President | Tamara Franz-Odendaal |
| Treasurer | Angelica Silva |
| Editor | Peter Wells |
| Librarian | (vacant) |
| Membership Officer | Jinshan Xu |
| Webmaster | Romman Muntzar |
| Publicity Officer | Brent Robicheau |
| Speaker Series Chair | Alana Pindar |
| Secretary | Hank Bird |
| Councillors: | |
| Councillor | Ann Dalziel |
| Councillor | Shannon Ezzat |
| Councillor | Bruce Hatcher |
| Councillor | Judy MacInnis |
| Councillor | Ali Shafiee |
| Councillor | Jeffrey Turner |

*Observers:*

| | |
|---|---|
| Nova Scotia Museum | Tim Fedak |
| Discovery Centre | Adam Brown |
| Schools | (vacant) |

*Student Representative:*

| | |
|---|---|
| MSVU | Ale Torres |
| SMU | Audrey Sanger |

*Associate Editor:* David Richardson

**17. Motion to Approve the Nominations:**
Moved: P. Ryall
Seconded: A. Dalziel
All in favour: Approved unanimously via online poll.

**18. Any Other Business:**

There was no other business to conduct. The meeting acknowledged A. Dalziel for setting up the hybrid (live & Zoom) meetings for this AGM and the following Public Lecture. David Richardson was thanked for his efforts to obtain the venue at SMU and set up the buffet dinner and refreshments. And the meeting expressed appreciation to the President of Saint Mary's University for the favorable rates we were granted for the facilities.

**19. Adjournment:**

Motion by S. MacQuarrie to adjourn the 162nd Annual General Meeting of the NSIS at 7:31pm.

*Respectfully submitted,*
*Hank Bird, Secretary*

# NSIS 2023-2024 LECTURE SERIES NSIS1862.CA

## October 16

### Exploring how our Environment & Genes Impact Colorectal Cancer Risk in Atlantic Canada

**Dr. Derrick Lee**
St. Francis Xavier University

There are many factors that influence an individual's risk of **cancer**. Dr. Lee will describe one of his research projects that takes aim at explaining why the risk of colorectal cancer is so high in our region.

## November 6

### Harnessing Waste Data to Mobilize Community Action

**Dr. Kathleen Aikens**
Atlantic Coastal Action Program

ACAP Cape Breton has been collecting data on **litter & illegal dumping** for more than a decade, through the Trashformers program.

Dr. Aikens will describe challenges & opportunities of this program, and the embedded educational goals of the work, from training students who lead the clean-ups to engaging the community.

## December 4

### Overlooked No More: Non-indigenous, Invasive Species in Nova Scotia Lakes & Rivers

**Dr. Linda Campbell**
Saint Mary's University

The unanticipated & unplanned appearance of **non-indigenous species in freshwater ecosystems** is a global issue.

Dr. Campbell will present case studies for both fish & invertebrates in N.S., highlight progress made over the past decade, and discuss ongoing needs in order to limit the impact of unwanted species on N.S.'s freshwater ecosystems.

## January 15

### Careers in Science: Panel Discussion with Nova Scotian Scientists

All lectures will be hybrid events held at St. Mary's University (Stephanie MacDonald Lecture Theatre, SMU Atrium 101) and on line via Zoom links that will be posted one week before each seminar on the NSIS Public Lectures webpage .

**1ST MONDAY OF EVERY MONTH 7:30 PM** @NSInstituteofScience @NSIS_Sci_NS

# NSIS 2023-2024 LECTURE SERIES NSIS1862.CA

## February 5

### Aiming to help 'Restore the Climate and Heal the Ocean': Preliminary Findings from a Groundbreaking Study of Marine CO2 Removal in Halifax

**Dr. William Burt**
Planetary Tech

Planetary Tech, a Dartmouth-based company, teamed with Dalhousie researchers, is leading global efforts to test a potential tool in the fight against both the **climate crisis** and **ocean acidification**. This talk will outline how this tool, called **Ocean Alkalinity Enhancement**, works, and explain how N.S. has become a well-recognized world leader in the tool's R&D.

## February 5

### Student Symposium:

Join us as we discover the latest research findings of **student scientists** working at nearby NS research institutions.

*We thank our partners who have joined us in our journey and mission to promote research and education in science...*

## April 8

### Sustainable Agriculture Needs Insects; Insects Need Sustainable Agriculture

**Dr. Paul Manning**
Dalhousie University

**Insects** are sometimes called "the little things that run the world" based on their central importance to terrestrial & freshwater ecosystems. This importance extends to land used for producing food, where insects provide a range of environmental benefits to **agriculture**.

Dr. Manning will explore the environmental benefits supported by insects; arguing that **insect conservation** is an integral outcome of **sustainable food production**.

## May 6

### The Geology of the Cabot Trail: The Surprising 1.5 Billion Year Story of Nova Scotia's Most Iconic Drive

**Dr. Jason Loxton**
Cape Breton University

Beneath the rolling vistas of the world-famous **Cabot Trail**, lies a story far older and more dramatic than most people imagine. A story of colliding **continents**, mass **extinctions**, **volcanoes, earthquakes,** and **glaciers**...

By tying the broad story of Nova Scotia's development as an Island to a series of accessible stops along the Cabot Trail, this talk will ensure you never experience the Cabot Trail the same way again!

# NOVA SCOTIAN INSTITUTE OF SCIENCE
# MEMBERSHIP FORM 2023-2024

Please fill out and make copy, then forward in mail together with membership fee.

Name: ______________________________________________

Address: ____________________________________________

____________________________________________________

____________________________________________________

Phone: H ____________________ W ____________________

Email: ______________________________________________

If this membership is being purchased on behalf of another individual, please insert that person's name here:

________________________________

**Memberships (please check one):**

Regular member $30 _____

Student member $10 _____

Life membership $300 _____

Enclosed is cheque for ___________ to cover dues for ____ years.

Voluntary Donation (Tax receipt will be issued): ___________

**Mail to:**

Attention: Treasurer, Nova Scotian Institute of Science
c/o Reference and Research Services
Killam Memorial Library | 6225 University Avenue
PO Box 15000 | Halifax, NS Canada B3H 4R2

**NSIS1862.CA**

# INSTRUCTIONS TO AUTHORS

The Proceedings accept original research papers, commentaries, reviews of important areas of science and science history, student award papers, and book reviews.

**Papers** may be submitted in either English or French and sent as a WORD document to the Editor, Dr. Peter G. Wells, at oceans2@ns.sympatico.ca, with a copy to nsis@dal.ca. Submission of a manuscript will be taken to indicate that the work is completely original, i.e., it is the author's own work and has not been published before, in part or in whole, and is not being considered by another publication. All authors of a submission must approve it prior to it being submitted. Please include this information in the submitted manuscript.

**Commentaries** are short (less than 2000 words) discussions of topical scientific issues or biographies of prominent regional scientists who have been members of NSIS.

For **review papers**, authors wishing to include figures, tables, or text passages that have already been published, must obtain permission from the copyright owner(s) prior to submission. Please include this information in the submitted manuscript.

***PAPERS SUBMITTED ARE TO STRICTLY FOLLOW THE INSTRUCTIONS BELOW. IF NOT, PAPERS WILL BE SENT BACK TO AUTHOR TO UPDATE.***

**FOR THE GENERAL LAYOUT OF PAPERS, REFER TO RECENT ISSUES OF THE JOURNAL.** Pages of the submitted WORD document should be numbered. **PROVIDE A RUNNING HEAD FOR THE PAPER.**

The **title** should be followed by names, addresses and e-mails of all authors. A footnote with an asterisk and worded: "*Author to whom correspondence should be addressed:", with the relevant email address, should be placed at the bottom of page one of the manuscript.

An **abstract** of up to 200 words should follow, together with a list of five keywords or less.

As appropriate, **sections within the paper** entitled Introduction, Methods, Results, Discussion, Conclusions, and References should follow. Canadian spelling and SI units should be used wherever possible. References cited in the text in brackets should be separated by commas and personal communications should be as follows: Smith A.J. (2001, pers. comm.). *Latin* or *scientific* names should be in italics, as well as abbreviations such as *et al.* **PLEASE GO OVER YOUR PAPER TO AVOID ERRORS OR DELETIONS. SPELL CHECK THE ENTIRE PAPER BEFORE SUBMITTING.**

All **tables, figures, photographs** and **other illustrations** should be numbered and have a self-explanatory caption. **THEY ARE TO BE ATTACHED TO THE SUBMISSION AS SEPARATE HIGH RESOLUTION FILES AND NOT EMBEDDED IN THE WORKING WORD DOCUMENT. DO NOT SEND PAPER AS A PDF.** Authors should indicate where each item might be placed in the manuscript.

Authors are encouraged to submit **figures, photographs** and **illustrations** in colour. Colour versions will be placed on the NSIS website and in the PDFs provided to authors. **Black and white versions will be in the print copies, unless color output is otherwise requested. There will be a charge ($10 per page) containing color in the printed papers.**

**REFERENCES ARE TO BE IN ALPHABETICAL ORDER – NAME FIRST, FOLLOWED BY INITIALS, WITH NO SPACE BETWEEN INITIALS.** For cited papers, **GIVE THE FULL TITLE OF THE JOURNAL (IN ITALICS)**, volume and issue numbers where appropriate. Examples of formatted references, covering monographs, chapters in monographs and papers, and with close attention to spacing, follow:

**Cushing, D. & Walsh, J.** (1976). The Ecology of the Seas. W.B. Saunders Company, Toronto.

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