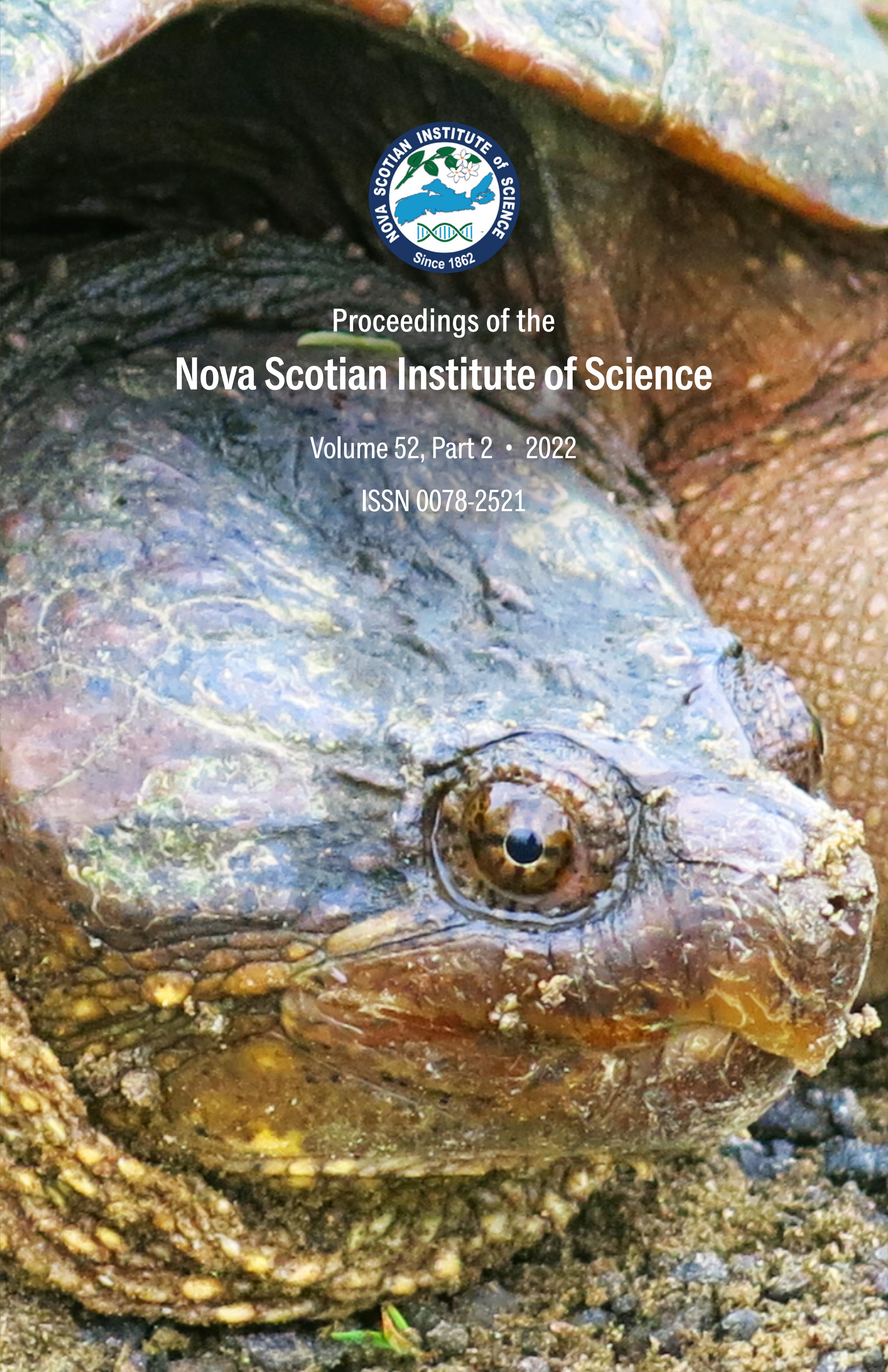

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Cover photo credit: A female Common Snapping Turtle, *Chelydra serpentina* – photo taken at Annapolis Royal, NS, near the treatment pond, Spring 2016 (Peter Wells).

Back cover inset photo credits: Top: Lichens and mosses colonizing the trunk of a deciduous tree at Long Lake Provincial Park (Peter Wells); Centre Left: Common Loon, *Gavia immer*, Brünnich (Derek Kerekes); Centre Right: View from the shoreline in Long Lake Provincial Park, NS, an unspoiled wild space in the Halifax Regional Municipality (Peter Wells); Bottom: A female Common Snapping Turtle, *Chelydra serpentina* – photo taken at Annapolis Royal, NS, near the treatment pond, Spring 2016 (Peter Wells).

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Continued

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EDITORIAL

Challenges for science and society in an era of rapid environmental change – a role for the NSIS?

This Issue of the PNSIS has contributions on a wide range of topics, from marine chemistry to ecological research in wilderness areas of Nova Scotia. The commentary on ocean health is especially noteworthy, as it brings attention to the region's ocean science sector, and the vital connection between ocean and human health. The papers in the PNSIS and our monthly NSIS talks illustrate the wide range of local scientific expertise and output and how it contributes to our society's knowledge, well-being and productivity.

Science has been the key to the human and social enterprise of the 19th and 20th centuries (Dubos 1970). It has shaped the modern world at a time of a major population increase, brought on by better living conditions and medical care, vaccines and the increase in available food. At the same time, there have been continued human tragedies as a result of wars, pandemics, mass migrations, and starvation related to social unrest and localized food shortages. Despite such challenges, much progress to improve the human condition since WWII has been facilitated by the United Nations and its many front-line agencies.

On this theme, it is well worth reflecting back 50 years to the pivotal conference on the environment, held in Stockholm, Sweden – the 1972 United Nations Conference on the Human Environment (Ward and Dubos 1972). It was the first of its kind to discuss the environment from a global humanities perspective. It came as a result of the waves of public concern about the environment that began in the 1960s. This was spurred on by the over-riding threat of nuclear war, an awareness of the spread of persistent toxic chemicals (Carson 1962), and as already mentioned, concerns about the rapidly increasing human population, at that time being 3.5 billion (Ehrlich 1968, Regier and Falls 1969, Meadows *et al.* 1972, amongst others) and now close to reaching an alarming 8 billion.

At the Stockholm conference, in addition to important discussions of the above global concerns, it was already noted that rising CO_2 levels from man's activities could lead to a significant rise in the earth's temperature, from 0.5 to 2 ^{0}C, i.e. climate change (Ward and Dubos 1972). This conference helped to put the environment on the political agenda and encouraged many countries to establish environment departments. It also led to the establishment of the United Nations Environment Program (UNEP) and important conventions such as MARPOL '73/'78.

The Stockholm conference was successful by most accounts. "The participants adopted a series of principles for sound management of the environment including the Stockholm Declaration and Action Plan for the Human Environment and several resolutions. The Stockholm Declaration, which contained 26 principles, placed environmental issues at the forefront of international concerns and marked the start of a dialogue between industrialized and developing countries on the link between economic growth, the pollution of the air, water, and oceans and the well-being of people around the world" (https://www.un.org/en/conferences/environment/stockholm1972).

Since 1972, there have been many follow-up international meetings, notably Rio 1992 (producing Agenda 21), Johannesburg (2002), and Rio 2012 (PEW Environment Group 2012). Progress has been made on some issues, less or none on others. There is a follow-up meeting this year in Stockholm, celebrating its 50th anniversary and emphasizing the need for urgent action on a range of environmental problems, many of which remain the same!

Hence, much more needs to be done and done on a continuous basis. This is especially true where land and water pollution, habitat (e.g., forests) and biodiversity loss, the spread of invasive species, fresh water shortages, and rapid climate change continue unabated (e.g., WWF 2017), despite much effort over past decades.

Fortunately, in recent years in the western world, public figures and writers such as Attenborough (2020), Suzuki (DSF 2008) and others (Wallace-Wells 2020, Wilson 2016, Wadhams 2017) have kept the major environmental issues and opportunities in the public eye, despite other problems that face us (e.g., inflation, new wars, the global COVID pandemic, food shortages, and mass migrations). Caring for the environment and for species other than ourselves is now seen to be in the public interest but it is a constant and seemingly overwhelming challenge to maintain this focus. It is difficult to stay optimistic (Attenborough) and easy to be completely overwhelmed and pessimistic (Wallace-Wells). On a personal note, I have adopted the philosophy of "the despairing optimist" (Dubos 1970) as one must have hope for the future, despite the challenges.

This editorial is obviously aimed at the readers of the PNSIS and other concerned citizens of our province. How can the NSIS build on the momentum brought on by Stockholm and subsequent conferences, and bring these issues, challenges and discussions of solutions more effectively to public attention? More importantly perhaps, how do we productively engage people, including politicians and decision makers at all levels of government? How can the NSIS and its membership, and its followers as a whole, more effectively consider and debate the key issues related to how science can better serve society in these very turbulent times? How can the NSIS track progress and also work to speed up the process towards solutions?

To ignore the state of the environment, especially climate change, and not act individually and as an organization is to 'let Rome, i.e. Planet Earth, burn' and to compromise the well-being of our children and future generations! Climate change in our region in particular must continue to be seriously addressed and without delay (Lane 2020, among others), along with other environmental issues confronting Nova Scotia (see articles in the CSEB Bulletin, e.g., Wells 2022). All of them demand public and political attention and an active interplay of science, information, policy/decision making, and timely and effective management (see www.eiui.ca, Wells 2021).

The broad mandate of the NSIS is to inform society on the advancements and applications of science for a better and sustainable world, with a focus on the Maritime region. Engagement of members and open discussion of our individual and combined roles will show if we are being successful, in the spirit of the 1972 Stockholm meeting and its goals. As well, we could invite provincial Ministers to present their plans for future environmental legislation, followed by a question and answer session, or send an NSIS delegation to the legislature to meet with politicians and senior bureaucrats to express our concerns and argue for more action on the environmental front. New ideas and approaches are needed, especially from the NSIS membership.

To conclude, 2022 is also the 50th anniversary of the International Ocean Institute, established through the efforts of Professor Elisabeth Mann Borgese of Dalhousie University. Her efforts to establish the UNCLOS III ocean governance treaty in 1982 and to apply it globally in principle and practice, in the interests of global peace and prosperity, have been recognized (Werle *et al.* 2018, Meyer 2022). This underlines the importance of the ocean for living resources (i.e. food), transportation, mineral resources, climate control, international peace, and human health and welfare. It is also noteworthy that the recent G7 meeting in Europe has issued a major statement about its policy commitment to the global ocean (Anon. 2022). It is encouraging that many key politicians are aware now of the climate change crisis and the state of the ocean around the world. Hopefully their administrations will follow such policy statements with meaningful and immediate action. In the spirit of the Stockholm Conference of long ago, let's rally the NSIS and collectively contribute through science and action to a healthier and more sustainable Maritime region and world.

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A TRIBUTE TO DR. ARCHIBALD WILSON McCULLOCH, FORMER NSIS PRESIDENT AND NRC RESEARCH SCIENTIST

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Dr. Archibald Wilson "Archie" McCulloch (October 31, 1940-September 3, 2019) was a former Director of Chemistry at the National Research Council of Canada's Institute for Marine Biosciences in Halifax, NS. Born in Troon, Scotland, he received his secondary education at Marr College, Troon. He graduated from the University of Glasgow in May, 1962, with a B.Sc. in Pure Science with First Class Honours in Chemistry, and was named a Fellow of the Chemical Society, London, in the same year. He continued at Glasgow for his Ph.D. (1965) in organic chemistry, supervised by Dr. N.J. McCorkindale, his thesis being entitled "Studies on Hydroxyisoquinolines". He came to Canada in October, 1965, to take up a postdoctoral fellowship with Dr. A. Gavin McInnes, Head of the Natural Products Chemistry Section at the National Research Council's Atlantic Regional Laboratory (NRC-ARL) in Halifax. His research with others in the Section at NRC-ARL produced a series of papers on many topics in organic chemistry, including the influence of Lewis Acids on Diels-Alder reactions, natural product derivatives including muconic acids, fusarubins and related antibiotics, biosynthetic studies of caerulomycins, and studies of silica production by diatoms. He was awarded a Fellowship of the Chemical Institute of Canada in 1980.

In 1987 the then Director (later Director General) of NRC-ARL, Dr. Roger Foxall, appointed Dr. McCulloch as Head of the Natural Products Chemistry Section following the retirement of Dr. McInnes. Shortly thereafter, NRC-ARL became part of an inter-laboratory effort to determine the cause of an episode of serious human poisoning after consumption of some mussels harvested in Prince Edward Island. Along with Dr. Jeffrey Wright and some other

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ARL section heads, Dr. McCulloch helped to mobilize the capabilities that had been built up over many years to determine structures of natural products. They proposed bioassay-guided fractionation as a means of narrowing down on the toxic substance, subjecting samples of toxic and non-toxic mussels to identical fractionation procedures, and testing each fraction for toxicity using a mouse bioassay temporarily set up at ARL by the Department of Fisheries and Oceans. Ultimately, this resulted in definitive identification of the toxin (domoic acid) within 4 days of installation of the bioassay. Subsequent work established analytical procedures for sensitive quantitative detection of the toxin and showed that it was produced by an algal (diatom) species that had bloomed in the area of PEI where the mussels had grown. The episode demonstrated the vulnerability of the molluscan shellfish industry to marine toxins and resulted in the establishment of a continuing research focus on marine natural toxins at NRC-ARL. This covered virtually all aspects from the identification of new toxin types and their producing organisms, biosynthesis, structural characterization of toxin molecules and variants, development of chromatographic and other analytical techniques for their isolation and sensitive detection, and production of analytical standards.

Following the appointment of Dr. Pierre Perron as President of NRC in 1989, major changes were made to the administrative structure of the Halifax NRC laboratory. The eight "sections" were replaced with two divisions, Chemistry and Biology, in 1991. Dr. McCulloch was appointed Director of Chemistry alongside Dr. John van der Meer as Director of Biology. At about the same time, the name of the Laboratory was changed to "NRC Institute for Marine Biosciences" (NRC-IMB), reflecting a major change of research direction and the winding down of some disciplines such as Lichenology, Biophysics and Ceramics (formerly High Temperature Chemistry) which did not fit readily within Dr. Perron's vision that each NRC institute should have an identifiable focus. The subsequent years were turbulent. The change of federal government in 1993 was followed by stringent austerity measures with major budget cuts, layoffs and retirements of staff, and appointments of new Research and Technical Officers specializing in fields related to fish aquaculture, fish nutrition, shellfish aquaculture and genomics. Much of the thankless job of administering these changes fell to Dr. McCulloch, who managed to shield those in his charge from the day-to-day aggravations, thereby enabling their research to continue and even flourish, but leaving very little time for his own research. A cancer diagnosis in 1997 unfortunately hastened his retirement from NRC in 1998.

Subsequently, having undergone successful treatment, he volunteered for many years with the Canadian Cancer Society, where his administrative skills were soon recognized by appointment to many national committees. Many other organizations benefited from his effective volunteer services. The breadth of his interests was also exemplified by his authorship of a profile of Sir John William Dawson (1822-1899), a noted Nova Scotian scientist (McCulloch 2010). A keen and artistic photographer, Archie was a long-standing member of the Photographic Guild of Nova Scotia, serving as its President in 1993 to 1995. His other hobbies included stamp collecting, golf, curling and tennis. Archie was devoted to his wife Elaine, their sons John and Scott, and three grandchildren, and greatly enjoyed opportunities to retreat to their family cottage at Eight Island Lake in Guysborough County, NS.

Archie was an active Council member for the Nova Scotian Institute of Science from 2002 to 2006 and a regular attendee at the monthly meetings. He was elected President for 2003-2004. While he published widely in international journals, just two of his papers were in these Proceedings (PNSIS), the one mentioned above on Dawson, and a second paper describing a long term, collaborative study over 27 years of sea trout in Nova Scotia (Whiteway and McCulloch 1995).

In summary, Archie will be remembered for his meticulous research skills, clarity of thought, careful writing, and unfailing kindness, courtesy and directness in dealing with all his colleagues and acquaintances.

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THE OCEAN AND HUMAN HEALTH AS A META-DISCIPLINE: OPPORTUNITY FOR ATLANTIC CANADA

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ABSTRACT

The one global ocean is receiving unprecedented attention recently, due to numerous factors such as the ocean's role in climate change and the burgeoning blue economy. However, even though the ocean allows life on this planet, very little attention has been given to the complex relationship between the ocean and human health (OHH). USA and Europe have for a number of years focused funding on OHH as a meta-discipline (i.e., a discipline that includes the ideas and perspectives of a number of other disciplines), but Canada until now has not. This article examines the advancement of OHH and argues that Atlantic Canada could and should lead a Canadian meta-disciplinary program on the ocean and human health.

Keywords: global ocean, human health, meta-discipline

INTRODUCTION

Covering 72% of Earth, this single connected vast body of water known as the global ocean allows us to live on this planet. It accounts for 97% of the water, contains at least 96% of Earth's living space, and generates approximately 50% of the atmosphere's oxygen. It has cushioned the blow of climate change by absorbing close to a third of all anthropogenic carbon emissions and >90% of the heat added to the global system (IPCC 2014); it also influences our weather and provides food for billions of people. The ocean and its resources define a part of our common heritage which is a critical part of many cultures (Ocean Atlas 2017).

Of late, the ocean is receiving unprecedented attention, presumably fueled by at least two factors: 1) increasing acceptance of climate change as the greatest existing threat to humanity, coupled with the recognition (finally) that the ocean is both a driver and recipient of climate change impacts (IOC-UNESCO 2022);

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and 2) skyrocketing interest in the ocean's potential to generate income, or the 'blue' economy, whether sustainable or not (Watson-Wright 2022, McCauley 2022). The burgeoning interest in the blue economy is in turn being stimulated by several elements. The value of marine activities globally was assessed by OECD at 2.5% of global GDP, or about 1.5 trillion US dollars, with estimates that the ocean economy will double by 2030 to $3 trillion USD for 5% global GDP (OECD 2016). Shipping by sea moves 90% of all goods in the world, while more than 40% of the human population lives in the coastal zone (UN Ocean Conference 2017), with projections that this number will reach 75% within this decade (UNESCO 2022). Fisheries provide more than 3.3 billion people with an estimated 20% of their average per capita intake of animal protein, and fisheries and aquaculture provide employment for more than 60 million people worldwide. Of course, the ocean supports many industries, not only fisheries and aquaculture, but also shipping, oil and gas, marine and coastal tourism (including cruise ships), submarine cables and pipelines, dredging, ports, offshore renewable energy beyond wind, such as waves and tidal, mining, pharmaceuticals, and more (IOC-UNESCO *et al.* 2011). All this activity means the ocean is facing threats from numerous stressors – globally, regionally, and locally (IOC-UNESCO 2022) (Fig 1).

THE OCEAN AND HUMAN HEALTH (OHH)

As the world's human population has increased to more than 7.8 billion today (US Census 2022), concerns about the range and intensity of threats to human health and well-being, arising in and from the ocean, have grown. Numerous studies have identified various issues such as marine pollution, overfishing, hypoxic dead areas, harmful algal blooms, coastal flooding and an increased frequency and intensity of extreme storms related to climate, among others, as serious dangers to the health of the global ocean, and consequently to humans (see Fleming *et al.* 2019). As outlined by Wells (2018), the list of stressors is long, creating a plethora of 'wicked' problems in the quest to find workable solutions for ocean protection. In addition, we understand little of the combined effects of those stressors beyond accepting that the collective impact often exceeds the sum of individual stressors (IOC-UNESCO 2022).

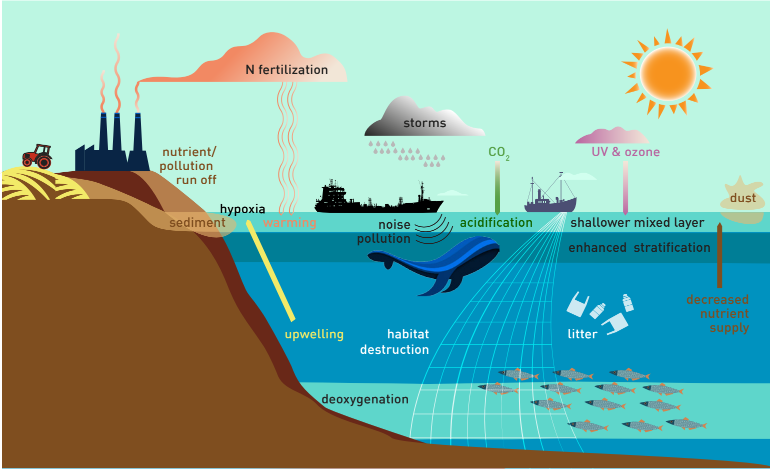

Fig 1 **Illustrative examples of global (warming, acidification), regional (ozone, litter, atmospheric pollutants) and local (sedimentation, pollution and nutrient runoff) stressors, all of which can affect marine life (after IOC-UNESCO, 2022; adapted from Boyd *et al.*, 2018)**

The ocean and coasts affect everyone, even those who do not live close to the sea (NOAA 2021). Despite this fact, the ocean and the many goods and services it provides have not traditionally been linked to human health. The health of the ocean itself has for many years and in many countries been assessed using the Ocean Health Index (OHI), which is a framework for rating ocean health based on the sustainable provisioning of benefits and services people expect from a healthy ocean (Halpern *et al.* 2020, Ocean Health Index 2022). However, the complex relationship between a healthy ocean and human health needs to be studied in a dedicated and holistic fashion (Borja *et al.* 2020, Bowen *et al.* 2014, Fleming *et al.* 2019, WHO 2019).

Peter Neill of the World Ocean Observatory perhaps articulated it best in saying that “the story of how human health and ocean health are related is not one easily told” (Neill 2017). In fact, the ocean and coastal seas are ‘like a double-edged sword’ when it comes to influences on human health (EMB 2013). Fleming *et al.* (2019) illustrated the complexities of these influences (Fig 2), and underlined that the many interactions attributed to increasing numbers of humans living on or near the coasts combine in complex and multifaceted ways with the effects of climate change (Fleming and Laws 2006).

In terms of risks to human health, stressors include but are not necessarily limited to: agricultural and sewage fecal waste runoff leading to nutrient enhancement; sea-level rise; tsunamis; storm surges; ocean acidification and warming which impact marine species upon which humans depend for nutrition; contaminants including chemicals, medical and veterinary pharmaceuticals; radionuclides; biotoxins from harmful algal blooms; sound and light pollution; climate change and extreme weather; increased UV-radiation; hypoxia; habitat disturbance (e.g. from commercial marine activities); microbial runoff, and others (EMB 2013). Depledge (2018) reminds us of our connections to the sea and that even though over 2.5 billion people live within 100 km of the coastline, we often fail to grasp the very real risks of the ocean to our health and well-being.

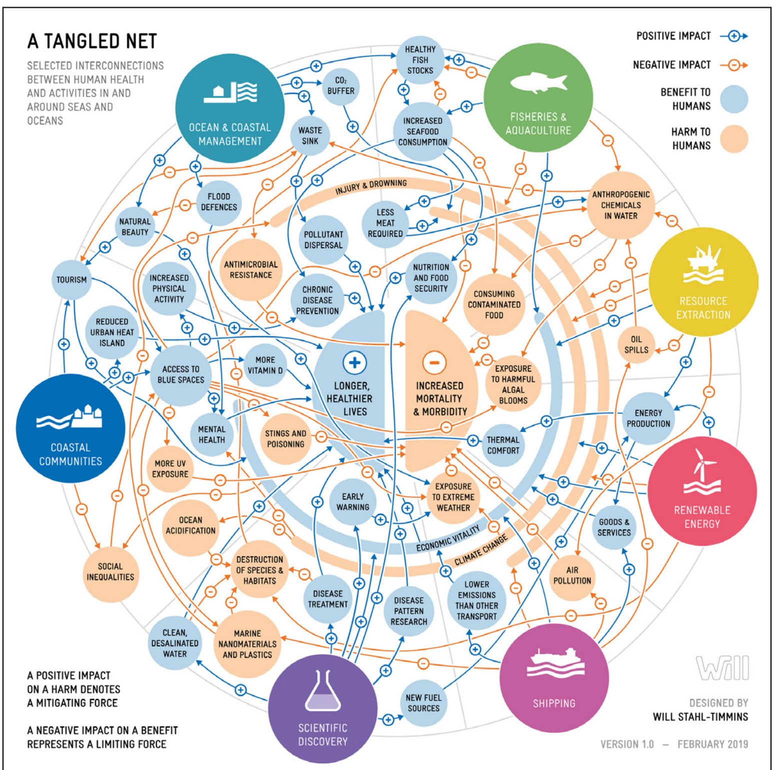

Fig 2 **Tangled net of ocean-human health interactions (after Fleming *et al.*, 2019) (link to Ocean Viewer found at https://besjournals.onlinelibrary.wiley.com/doi/full/10.1002/pan3.10038).**

Importantly, people in coastal communities, Indigenous populations and inhabitants in the high Arctic will bear the most serious of the ocean risks. As stated by Sexton (2020), "the very survival of these vulnerable populations depends on the health of the seas".

Yet the ocean also offers innumerable benefits to human health including 'non-market' services related to provisioning (e.g., food), regulating (e.g., climate), and culture (e.g., recreational) (Mapping Ocean Wealth 2022, Ganter *et al.* 2021, WHOI 2021). In addition to transportation and tourism, the ocean provides sustenance in the form of animal protein, nutrition in the form of vitamins, and jobs and income for many (Ganter *et al.* 2021). Creatures from the ocean have been used by scientists for many years to study diseases in humans (National Academies of Science 1999), with some serving as an early warning system or "sentinel species" for the health of the ocean and humans (Fleming and Laws 2006). An example of the latter is the long running Gulf of Maine Gulfwatch wherein blue mussels have been and continue to be monitored for the presence of chemical contaminants since 1991 (Gulfwatch 2022). Evidence is also increasing which emphasizes the role of the ocean in enhancing human physical health, as well as for providing for both mental and spiritual wellbeing, an effect described as the 'Blue Gym' (Depledge and Bird 2009, Nichols 2014, White *et al.* 2016). Interest in the blue gym effect has greatly increased in the past two years due to COVID-induced confinement and the resultant impacts on mental health. As well, pharmaceuticals derived from marine organisms are enhancing treatments for a wide variety of diseases such as cancer and HIV (Kijjoa & Sawangwong 2004, NOAA Ocean Exploration 2021, NOAA 2022), with recent heightened optimism that the ocean will provide new drugs for the fight against COVID-19 (Taglialatela-Scafati 2021) or the next pandemic (Robinson 2022).

COUNTRIES STUDYING OHH

The USA was the first to recognize the important relationship between the ocean and human health and its priority as a research topic as early as the 1970s. The publication by the National Research Council entitled *'From Monsoons to Microbes: Understanding the Ocean's Role in Human Health'* (1999) played a seminal role in advancing the topic and in having the ocean and human health recognized as a meta-discipline, i.e., a discipline that includes the ideas and perspectives of a number of other disciplines (Sandifer *et al.* 2013). The establishment of NOAA's Ocean and Human Health Initiative in 2003, creation of a national network of seven OHH centres of excellence the following year, and other events including the passage of the Oceans and Human Health Act (NOAA 2012) led to the firm embodiment of linkages between the ocean and human health in American ocean policy (EMB 2013). Indeed, the USA continues to dominate the ocean and human health research arena with 49.3% of research articles from 1990 to 2017 relating to US populations (Short *et al.* 2021).

The EU took a page from the USA with the publication of the European Marine Board's 2013 position paper 19, '*Linking Oceans and Human Health: A Strategic Priority for Europe*' (EMB 2013). The main recommendation of this paper was to develop and support a consolidated European ocean and human health research programme to improve understanding of the potential public health benefits from marine and coastal ecosystems, to lower the burden of marine-related human disease, and to prevent serious new threats to public health. Subsequently, the Horizon 2020 program funded the SOPHIE project (Seas, Oceans and Public Health in Europe) from 2017 to 2020. Part of the project involved elaboration of a strategic research agenda (SRA) which focused on the three areas of: sustainable seafood and healthy people; blue spaces, tourism, and well-being; and marine biodiversity, biotechnology, and medicine. The SRA outlined policy needs, relevant research requirements, public and stakeholder attitudes, and capacity and training necessities (H2020 SOPHIE Consortium 2020). SOPHIE also published a policy brief that presented six recommendations, including promoting and supporting the development of a 'Health in All Policies' (HiAP) approach in marine and maritime initiatives (McMeel *et al.* 2019). Fleming *et al.* (2021), in the context of the UN Decade of Ocean Science for Sustainable Development, have since called for the development of an OHH action plan involving a multitude of different types of actors (from citizens to researchers to large international groups to policy makers) and offered thirty-five possible first steps to help kick start such a plan.

CANADA AND THE OCEAN

Canada has long considered itself a Maritime nation. Beginning with Confederation, it defined itself as a fishing and shipping nation, and its Fisheries Act of 1868 remains one of Canada's strongest pieces of federal environmental legislation. With by far the world's longest coastline – 243,042 km (Canada Yearbook 2011) which is four times longer than next nearest country (Indonesia) – Canada's ocean estate covers a surface area of approximately 7.1 million square kilometers or 70% of its land mass (Fisheries and Oceans Canada 2018). And while the great majority (90%) of the population is concentrated within 160 km of the US border, as of 2016, 14.5% of Canada's population or 4.8 million people lived within 10 km of the west, east, and north coasts, with an additional 4% living within 100 km (Ganter *et al.* 2021).

Canada has also been an acknowledged leader in global ocean issues and events. It was Canada who at the Rio Earth Summit of 1992 suggested celebrating a World Ocean Day, and who via UNESCO proposed the International Year of the Ocean, or YOTO, which was hosted by Portugal in 1998. In addition, Canada became the first country to pass an Oceans Act (in 1997) followed by an Ocean Strategy and Ocean Action Plan. More recently, among other things, Canada introduced the Charlevoix Blueprint (2018) along with the Ocean Plastics Charter (2018) during its presidency of the G7, is leading the Ocean Observations Action Group of the Commonwealth Blue Charter, is a member of the High Level Panel for a Sustainable Ocean Economy (2022) and co-hosted with Kenya and Japan the first global Sustainable Blue Economy conference in Nairobi in 2018.

Activities dependent on the ocean contribute substantially to Canadian provincial, regional, and national economies. Ocean-related industries in 2018 employed about 298,333 Canadians and contributed more than $36.1 billion of GDP in 2018, or 1.6% (Ganter *et al.* 2021), which, while substantial, is well below the aforementioned global 2.5% (OECD, 2016). The marine sectors involved include not only fisheries and seafood processing, but aquaculture, shipbuilding, marine transportation, port activities, marine science and technology (including biotechnology), tourism, offshore energy, and a wide range of service industries that support these activities. Not surprisingly, Canada has most recently embarked upon the development of its own Blue Economy Strategy (Fisheries and Oceans Canada 2022).

CANADA AND OHH

Despite its leadership on ocean issues, Canada has been largely absent in focusing integrated attention on the topic of the ocean and human health. Inspection Services of Fisheries and Oceans Canada (DFO)(now part of Canadian Food Inspection Agency) and Health Canada were long involved in the investigation of human illness related to ingestion of microbially- or biotoxin-contaminated seafood (see, for example, Todd *et al.* 1993, Watson-Wright *et al.* 1992), and one relatively modest program, Coasts Under Stress (2000-2005), looked at long- and short-term impacts of socio-environmental restructuring on the health of people, their communities, and the environment (Coasts Under Stress 2022). However, apart from these narrowly based activities, little else has happened. In fact, according to Short *et al.* (2021), between 1990 and 2017, only 5.5% of papers on OHH arose from Canada, but this was in comparison to only three other countries (USA, Australia, New Zealand) plus Europe. Recently, Kenny *et al.* (2020) have offered a very considered, thoughtful and well-researched perspective on the topic of the ocean and human health in this country, pointing out that 'no dedicated OHH initiatives exist in Canada' even though individual Canadian scientists have helped in establishing OHH as a meta-discipline. They call for a holistic climate-sensitive agenda for research, education, training, policy, and practice on OHH in Canada (Kenny *et al.* 2020).

WHAT ABOUT ATLANTIC CANADA?

The ocean plays a far more central role in Atlantic Canada than in the rest of the country. The majority of Atlantic Canada's population lives in or near coastal communities where ocean-related activities make up 6, 10, 14 and 40% of GDP respectively in New Brunswick (NB), Prince Edward Island (PEI), Nova Scotia (NS) and Newfoundland and Labrador (NL) (Mills, 2021), much greater than Canada's 1.6% and larger for each Atlantic province than for British Columbia (BC) (4.2%) (Ganter *et al.* 2021). In fact, 75% of Canada's ocean economy takes place in Atlantic Canada, along with two thirds of the jobs in fishing and aquaculture, 67% of defense jobs, and all the economy and jobs in offshore oil and gas (Ganter *et al.* 2021). Regarding ocean technology alone, the clusters of ocean technology companies in Atlantic Canada are considerable compared to the rest of Canada. The Atlantic Provinces represent roughly 6.5% of the population but nearly 60% of the Ocean Enterprise businesses. Compared to British Columbia, the Atlantic Provinces have roughly 5.5 times more companies per capita (COVE 2020). Thus, the ocean is very much top of mind to Atlantic Canadians – it is disproportionately important to us.

Our health matters a great deal too, but the Atlantic Provinces do not fare well as a region compared to the rest of Canada. According to a 2015 health status report by the Conference Board of Canada, Nova Scotia, PEI and New Brunswick received A's for self-reported health and self-reported mental health, but their overall health marks are dramatically different with PEI receiving a B, New Brunswick a C, and Nova Scotia a D. Newfoundland and Labrador ranked last among the provinces – only the territories fared worse (Conference Board of Canada 2015).

Given Canada's renewed interest in the ocean as well as the global population's focus on human health, now seems to be the time for a targeted Canadian meta-disciplinary research effort on the ocean and human health, and Atlantic Canada certainly seems to have the wherewithal to lead such an initiative. We have the largest concentration of ocean research institutes in the country, with active participation by Indigenous communities growing each year. Medical schools exist already in NS (Dalhousie University), NB (Dalhousie Medicine at UNB; Centre de formation médicale du Nouveau-Brunswick at Université du Moncton), and NL (Memorial University) and with the recently announced partnership between UPEI and Memorial University, will also be in PEI by 2024. Faculties of health and health sciences are prominent in many universities in all 4 provinces as are schools of environmental science. As stated above, Atlantic Canada hosts many ocean industry leaders as well as large initiatives such as the Ocean Supercluster, the Centre for Ocean Ventures and Entrepreneurship (COVE), the Ocean Frontier Institute, the recently announced PEI Bioscience Manufacturing Incubator, and others. And we have already begun to examine the Ocean Health Index approach in the Bay of Fundy (Kidd 2016) which could and should be expanded to look more at human health measures.

CONCLUSION

That ‘Canada is back’ regarding ocean leadership is a welcome occurrence here and around the world. And given its geography, talent, processes and current political will, Canada in general and Atlantic Canada in particular have a golden opportunity to again make our mark on ocean issues, especially that of the ocean and human health. A meta-disciplinary program on OHH seems like a perfect candidate for the Tri-Council New Frontiers in Research Fund whose Transformation stream "…provides large-scale support for Canada to build strength and leadership in interdisciplinary and transformative research" (New Frontiers in Research Fund 2022). In fact, although still reasonably narrow, a good start has already been made with the funding of the Memorial University-led project, *Repurposing Marine By-Products or Raw Materials for the Development and Production of Functional Foods and Bioactives to Improve Human Health and Coastal Community Sustainability.*

As stated by Fleming *et al.* (2019) "…the current and future state of the Global Ocean will in large part determine the current and future sustainability, health and well-being of all humans on Earth." Atlantic Canada has what it takes to lead a broad Canadian meta-disciplinary initiative on OHH to help ensure that sustainability. Will we rise to the challenge?

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LOON WATCH – 25 YEARS OF SUCCESSFUL VOLUNTEER CITIZEN SCIENCE AT KEJIMKUJIK NATIONAL PARK, NOVA SCOTIA

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Stemming from previous research, in 1988 the Canadian Wildlife Service (CWS), part of Environment Canada, launched a new study of the abundance and distribution of water birds in Kejimkujik National Park and National Historic Site (Kejimkujik) (Kerekes 1990a). The emphasis was on the Common Loon (*Gavia immer*) on Kejimkujik's lakes and was within the ongoing long-range transport of air pollutants (LRTAP) program. This Common Loon population study in later years attracted other investigations of the Common Loon on the same lakes (Burgess *et al.* 1998, Nocera &Taylor 1998, Hope 2006).

Dr. Joe Kerekes viewing a loon nest at Kejimkujik National Park, during a summer of the Loon Watch. Photo credit: Peter Hope.

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The study, which lasted from 1988 to 1995, when it was terminated by the CWS, included 25 lakes that were of sufficient size to support breeding loons. Within Kejimkujik, the 25 chosen oligotrophic lakes hosted a stable population of 39 pairs of Common Loons (Kerekes 1990b, 1998, 2002, Kerekes *et al.* 1995). It was determined that lakes greater than 20 hectares could support at least one pair of loons. Lakes greater than 40 hectares could support more pairs of successfully nesting loons. Lakes greater than 80 hectares could support more pairs. Successful reproduction of loons was closely associated with lakes that had a greater amount of fish biomass (Kerekes *et al.* 1994).

In 1995, it was decided to include volunteers to help with the study, surveying the lakes simultaneously. Twenty-one people were assembled by Joseph Kerekes and Peter Hope on a nice day in August. It included some park staff, CWS researchers, and volunteer friends of Kejimkujik. They dispersed over 14 different lakes to count loons seen within a specified time period. The event was a success and this approach began in earnest in 1996 under the name of Loon Watch.

Loon Watch, from the very beginning, depended upon volunteers ("citizen scientists" has recently been the title coined for such participants). Park staff member Peter Hope had many contacts with park visitors and set out to recruit people who would bring their own canoe and related equipment, plus binoculars. From the very beginning, standardized forms were used and every Loon Watch began with a meeting where details of identification of loon chicks, surveying time, and data forms were discussed. Each team was assigned a lake or portion of a larger lake. The meeting ended shortly after 10:00 AM to allow all surveyors to reach their assigned lake.

Many teams had to travel back-woods roads, some had to canoe and portage to reach their survey lake. The survey itself had to be done within three hours from 12:00 noon until 15:00 h on the specifically chosen Loon Watch days. Each year, the first Loon Watch took place in late May or early June to determine the distribution of adult birds and also to record any incidentally detected nests. The second Loon Watch occurred during the third week of August to document the distribution of adults and record details of all Common Loon broods. The age of the chicks, classified as downy, small or large young, was recorded. The survival of large young, at that late date in August, permitted yearly comparisons of the numbers likely to fledge.

LOON WATCH – 25 YEARS OF SUCCESSFUL VOLUNTEER CITIZEN SCIENCE

Many of the volunteers continued to take part over the years, so the program included a trained and familiar group of participants. All observations were made on standardized data sheets to record details about adult loons, nests of young loons, and even loons seen in flight. Peter Hope blended Loon Watch observations with other sightings throughout the summer, gathered incidentally by park staff and researchers. As a result, a clear picture of the loon population, the number of resident pairs, and the number and location of surviving chicks was made possible.

The Loon Watch program continues to this day, coordinated and documented by a succession of park staff including Chris McCarthy, Donna Crossland and Jennie Eaton. It has become a permanent part of the suite of Parks Canada monitoring programs to assess fresh water conditions in Kejimkujik. The goal now is to survey 18 lakes. However, the numbers of volunteers who turn up at times makes it possible to survey even more lakes.

Successful production of loon broods was found to be closely associated with lakes producing a greater amount of fish biomass (Kerekes *et al*. 1994). A study of breeding Common Loons in Ontario, in relation to lake pH and size, found that a shortage of food was the main reason for reduced breeding success on low pH lakes (Alvo 2009). The Kejimkujik study area is close to the sea and even the marginal habitats (20 hectares lakes) are always occupied every year, there are no unoccupied lakes. This may explain low breeding success compared to other studies in the interior of the continent where possibly only the best lakes have loons.

During the time period of the initial Loon Watch Programme, Burgess *et al*. (1998) of the CWS studied the effects of mercury on common loons in Kejimkujik. He found that the loons had elevated mercury concentrations and that this heavy metal was associated with reduced reproductive success. Nocera and Taylor (1998) studied many of the same lakes and found that young loons with elevated blood mercury concentrations sought rides on their parent's backs less frequently; this behaviour increased their energy expenditure and led to the chicks being less likely to fledge.

Many factors were noted that appear to impact the reproductive success of the loons at Kejimkujik. Lake size was critical. Occasionally, spring rain floods the nests and causes egg mortality. Predation also plays a significant role as Great Black-backed Gulls *(Larus marinus)* and Bald Eagles *(Haliacetus leucocephalas)* that patrol the lakes will prey on loons as witnessed in various Nova Scotia lakes and reported to Kerekes and Hope (Pers. comm, 2021). In addition, a variety of other avian and mammalian species can potentially prey on loon eggs. Darren Reid, the Freshwater Project Manager at Kejimkujik, reports that in 2018 chain pickerel *(Esox niger)* invaded Kejimkujik waters and have now spread to virtually all monitored loon lakes. Chain Pickerel have the potential to diminish fish stocks and to prey on loon chicks (D. Reid 2021, Pers. comm.).

After 30 years, the Kejimkujik Common Loon population remains stable on the approximately 18 lakes continuously surveyed. The number of adult pairs on those water bodies is essentially the same as first documented in 1988. The number of loon chicks alive in late August in the Kejimkujik lakes varies greatly from 1 to 15 chicks in any year. The higher number of chicks is assessed as exceptionally good but the conditions leading to this are poorly understood. The continuing Loon Watch may lead to a greater understanding of loon successes and of the impact of the invasive chain pickerel.

CONCLUSIONS

The ability of the adult loon pairs to produce young in Kejimkujik lakes appears to be as good as it was more than twenty years ago, as shown by the 15 chicks recorded on the August Loon Watch in 2018. These conclusions are only possible because of the successful long-term monitoring by the Loon Watch program. Loon Watch now regularly surveys 18 or more lakes, including 16 of the 25 originally surveyed lakes (Hope 2006, Kerekes *et al.* 2009). The data from all of these years have been collected by the eager volunteers who strongly support continuation of the study by paddling Kejimkujik lakes twice per year on the Loon Watch.

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CARBON CYCLING AND REDOX CHEMISTRY IN AN ANOXIC MARINE BASIN, BRAS D'OR LAKE, NOVA SCOTIA

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ABSTRACT

Measurements of oxygen, methane, pCO_2, total dissolved inorganic carbon, total alkalinity, sulphide and nutrients were made in June, October and December 2017 in Whycocomagh Bay, a small marine basin at the western end of the Bras d'Or Lake estuarine system in Cape Breton, Nova Scotia. Dissolved oxygen was absent in the deep basin, similar to observations made in the years 1974, 1995-1997, and 2009-2021. Profiles of total dissolved inorganic carbon and total alkalinity were largely consistent with the sulphate reduction of particulate organic matter, having a Redfield stoichiometry of 106C:16N:1.6P. The concentration of dissolved methane ranged between 19-35 nmol L^{-1} (727-1147% saturation) above the thermocline, and reached 34.74 µmol L^{-1}, (931,900% saturation) in the deep anoxic zone. The potential rate of microbial methane oxidation at the base of the oxycline, determined from an incubation experiment, was 0.34 µmol L^{-1} d^{-1}, potentially acting to mitigate the flux of methane to the atmosphere. Deep water H_2S concentrations ranged from 747 to 1,074 µmol L^{-1}, more than a tenfold increase since the 1995-1997 study, with substantial increases also in ammonium and phosphate concentrations, likely as a result of eutrophication over the last two decades. Whycocomagh Bay presents an opportunity to study extreme marine redox chemistry at an easily accessible site.

Keywords: Anoxic, methane, carbon cycle, carbon dioxide

INTRODUCTION

Human-induced eutrophication of estuarine and shelf waters is causing an increasing frequency of hypoxia, defined as oxygen

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concentrations below 2 mg L^{-1} or 63 µmol L^{-1}, as a result of the bacterial respiration of organic matter (Rabalais *et al*. 2010). The progression of oxygen depletion to hypoxia causes detrimental effects to marine ecological systems, being fatal to most fin fish and epibenthic invertebrates (Diaz and Rosenberg 2008). Anoxic conditions lead to the formation of reduced chemical species such as ammonium and hydrogen sulphide, which can be toxic to fish and other forms of aquatic life depending on concentrations and pH (Randall and Tsui 2002, Podger 2013, Vaquer-Sunyer and Duarte 2010). Oxygen depletion due to respiration also results in the formation of high pCO_2 and low pH conditions that lead to increased dissolution of calcium carbonate skeletons (Nienhuis *et al*. 2010). In addition, hypoxic and anoxic regions are associated with enhanced emissions of methane and nitrous oxide, greenhouse gases that are much more potent than carbon dioxide (Naqvi *et al*. 2010, Etminan *et al*. 2016). A better understanding of the biogeochemical processes and biological implications of hypoxia and anoxia will contribute to more reliable environmental predictions of anthropogenic effects, including aquaculture and climate change.

Eutrophic coastal basins and inlets that are prone to seasonal or permanent oxygen depletion have provided conveniently accessible sites in which to study the effects of hypoxia and anoxia on ecology and biogeochemical element cycling e.g. Saanich Inlet, British Columbia: Matabos *et al*. 2012; Boknis Eck, SW Baltic Sea: Bange *et al*. 2009. Here we describe carbon cycling and related chemistry in an anoxic marine basin in the Bras d'Or Lake estuary, Nova Scotia. This site was previously sampled during oceanographic surveys in 1972-74 (Krauel 1975), 1995-97 (Strain *et al*. 2001), and 2009-2021 (DFO, 2021), providing a valuable baseline record of chemical conditions against which we can reference changes that have occurred over the last five decades.

STUDY SITE

Whycocomagh Bay is a semi-enclosed embayment that forms part of the inland estuarine system known as the Bras d'Or Lake (or "Lakes"). Geographically restricted water exchange between the Lakes and the NW Atlantic ocean, and the complexity of water circulation within the Lakes limits the tidal range in Whycocomagh Bay to <5 cm, (although winds and barometric set-up and runoff may add 15 cm to the amplitude), and the flushing time has been estimated at 2 years (Petrie and Bugden 2002). A 48 m deep basin at the western end of Whycocomagh Bay provides the focus of this study (Fig 1). It is connected to the rest of the Bay by a broad, 6.5 m deep sill to the east, and a narrow, 2.7 m deep channel between the shore and Indian Island to the north (Fig 1). The Skye River provides the major source of freshwater to this site, entering the basin through the northern channel. This geomorphology and circulation restrict vertical mixing in the basin, resulting in a pronounced pycnocline that separates a 10-12 m thick surface layer from a stagnant, oxygen-depleted bottom layer (Krauel 1975, Gurbutt and Petrie 1995, Petri & Bugden 2002). Anthropogenic sources of organic carbon to Whycocomagh Bay include a sewage treatment plant serving the community of Whycocomagh, discharging up to 750m^3 of effluent per day, and a Steelhead trout farm with 5 to 25 open mesh fish pens of 20 m diameter deployed within the basin since 2011 (Fig 1).

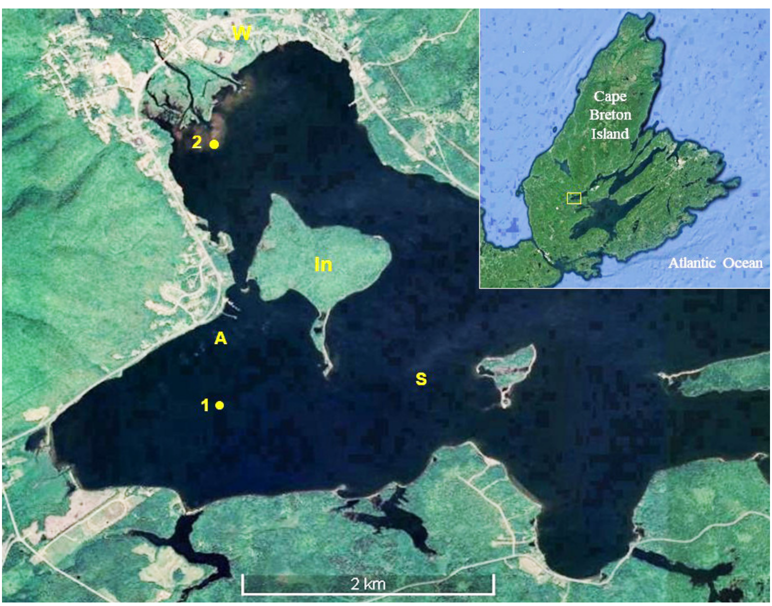

Fig 1 **The Whycocomagh Basin study area and location on Cape Breton Island, Nova Scotia (inset). Sample Site 1 (45.9460 °N, 61.1250 °W) lies above the centre of the deep basin while Site 2 (45.9648 °N, 61.1261 °W) is at the mouth of the Skye River. The community of Whycocomagh (W), Indian Island (In) and the approximate location of the aquaculture pens (A) and sill (S) are also indicated.**

METHODS

Water sampling was done in the centre of the basin (47.5 m depth, Fig 1) from a small vessel equipped with a winch on June 27, October 3, and December 4 and 5, 2017. Samples were collected at 8 depths in June and 9 depths for dissolved methane/pCO_2, oxygen, pH, total dissolved inorganic carbon (TIC)/total alkalinity (TA), hydrogen sulphide (H2S), and nutrients determinations in that order using 5 L Niskin bottles in conjunction with a SeaBird CTD (SBE-25 with oxygen). Water samples were also collected for a microbial methane oxidation (MOx) experiment. Additional samples were obtained from a site at the mouth of the Skye River on the 5th December 2017.

Dissolved oxygen, methane, carbon dioxide and ammonium

Samples for dissolved oxygen were drawn into gravimetrically calibrated 125 mL iodine flasks and immediately fixed by the addition of Winkler reagents, then stored in the dark until analysis within 24 hours. Dissolved oxygen concentrations were determined using a computer controlled Winkler titration with colorimetric endpoint detection after Jones *et al.* (1992). Oxygen saturation was calculated using the Bunsen solubility coefficients of Weiss (1970).

Dissolved methane and pCO_2 samples were collected in 125 mL serum bottles, preserved by the addition of mercuric chloride, and immediately crimp sealed with butyl rubber septa. CH_4/pCO_2 were later measured with a static headspace equilibrium method modified from Neill *et al.* (1997) where equilibrated headspace samples were injected into a gas chromatograph equipped with a catalytic methanizer and a flame ionization detector. Methane saturation was calculated using the Bunsen solubility coefficients of Weisenburg and Guinasso (1979). Total sulphide (H_2S + HS^- + S^{2-}) was determined within 24 hours of sample collection using the spectrophotometric methylene blue method of Cline (1969). H_2S, HS^- and S^{2-} are indistinguishable with this method and henceforth will be collectively referred to as H_2S.

CO_2 parameters

Total dissolved inorganic carbon (TIC) was measured according to Dickson *et al.* (2007) by purging acidified water samples with a stream of high purity nitrogen in an automated gas extraction system, the dried gas stream being analysed for carbon dioxide by coulometry. Total alkalinity (TA) was analysed by an automated open cell potentiometric titration with 0.1 N hydrochloric acid after Dickson *et al*. (2007). Seawater pH on the total hydrogen ion scale was determined at 25 ± 0.05 °C by a spectrophotometric method with purified m-cresol purple (Clayton and Byrne, 1993). Results for TIC, TA and pH were calibrated with measurements of a certified seawater reference material supplied by Andrew Dickson (Scripps Oceanographic Institution, San Diego, USA). pH and pCO_2 values were corrected to in-situ conditions of temperature and pressure using the CO2.SYS macro for Microsoft Excel (Lewis and Wallace 1998) with TIC as a second carbonate parameter and correcting for the effects of sulphide and ammonium.

Nutrients

Nutrient samples were measured with a segmented flow auto analyser following the methods described in Strickland and Parsons (1972) for nitrate, phosphate and silicate, and the fluorometric method of Kerouel and Aminot (1997) for ammonium. Reliable nitrate measurements are not available for the anoxic water owing to high levels of sulphide that interfere with the cadmium reduction method.

RESULTS AND DISCUSSION

Temperature and salinity

The upper 15 m of the water column displayed a wide seasonal variation in temperature, the surface water (1 m depth) ranging from 18.6 °C in June to 4.8 °C in December (Fig 2a-2c). Surface warming during summer and associated deepening of thermocline were followed by autumn cooling and wind mixing events, which seemed to cause the temperature inversion at 5-8 m in October. Continued cooling and more gradual mixing seemed to cause the inversion at 7-19 m in December. Below 23 m, the temperature remained constant at 3.16 °C during the three visits (Fig 2a). Surface and deep water conditions were similar to those recorded during 1996 and 1997 (Strain *et al*. 2001). In the latter case, bottom water temperature was in the range 2.94-3.23 °C, so it appears that warming of the deep basin has not occurred since then. However, slightly lower deep water temperatures (1.80-3.00 °C)

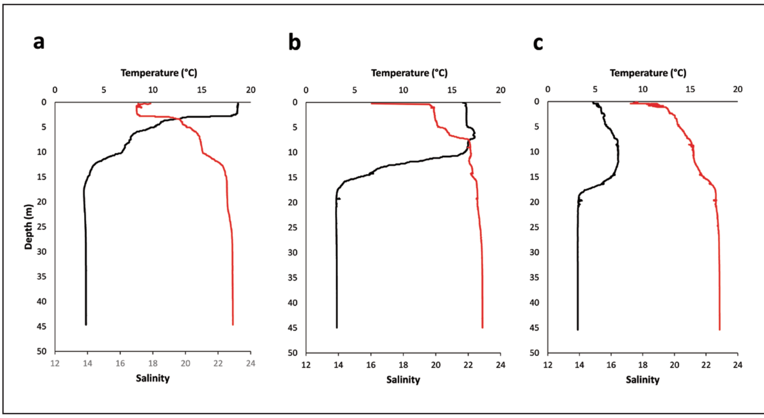

Fig 2 **CTD profiles of temperature (black line) and salinity (red line) in the Whycocomagh Basin measured in a) June, b) October, and c) December 2017.**

were reported in 1970's (Krauel 1975), so there may have been a small increase in the past.

In the case of salinity, freshening of the deep water mass is apparent, with 2017 values of 22.85 compared to 23.05-23.07 in 1996-97 (Strain *et al*. 2001), and 22.70-24.9 in 1972-74 (Krauel 1975). No sampling was undertaken in any study during January to April when ice typically forms over the northern Bras d'Or lakes, with the greatest extent of ice cover typically occurring in early March (Petrie and Bugden 2002).

Dissolved oxygen

The extent of molecular oxygen penetration into Whycocomagh Basin was at its greatest in June when the base of oxycline reached a depth of about 23 m (Fig 3a). A broad subsurface maximum of 352 µmol L^{-1} (106% saturation) at 10 m depth suggested a zone of maximal photosynthetic activity. A very similar profile was seen on June 2nd, 1997, where oxygen concentrations reached a maximum of 370 µmol L^{-1} at 10 m (Strain *et al*. 2001). A curious feature of the June profile was a small secondary peak at 19.5 m, potentially a result of low light photosynthesis. In October, the oxycline had retreated upwards to 14 m but with a sub-oxic zone extending down to about 19 m, and there was a near-surface maximum of 245 µmol L^{-1} (Fig 3b). This pattern continued in December but with increased concentrations throughout the upper 19 m, to a near-surface

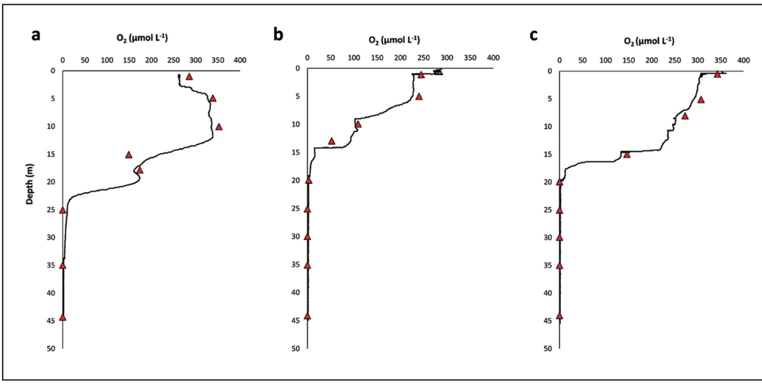

Fig 3 **The distribution of dissolved oxygen in the Whycocomagh Basin on 27th June (a), 3rd October (b) and 4th December (c), 2017. The solid black lines show CTD oxygen sensor profiles while red triangles represent Winkler measurements.**

maximum of 343 µmol L^{-1} (Fig 3c). At no time during the 2017 surveys could molecular oxygen be detected at 25 m or deeper. This finding is in agreement with the 1972-74 (Krauel 1975) and 1996-1997 (Strain *et al.* 2001) oxygen data, as well as with data from more than 80 profiles collected since 2009 (Hatcher, unpublished data). This deep basin has been continuously anoxic for half a century at least.

Carbonate system

The distribution of the carbonate parameters, TIC and TA, in gravimetric units of µmol kg^{-1}, plus pCO_2 and pH values corrected to in situ temperature and pressure, are shown in Fig 4. The concentrations of TIC and TA in the deep water were about two-fold higher than in the upper 20 m, while pCO_2 reached 6,665 µatm, or around 1,626% saturation based on an atmospheric mole fraction of 400 ppm. In the surface oxygenated water, TIC is controlled by the removal or addition of carbon dioxide resulting from the opposing effects of photosynthesis and respiration. About 1% of dissolved carbon dioxide reacts with water to form carbonic acid, H_2CO_3 which dissociates to form HCO_3^- that is in turn in equilibrium with CO_3^{2-} at a given pH. In either case, carbonate alkalinity (CA) is unaffected as the charge balance between protons and anions is maintained. The question therefore arises as to why TIC, and indeed pCO_2, is so high in the deep water in the absence of aerobic respiration. The underlying geology of the region may play a role in influencing TA as, prior to inundation through sea level rise, the Bras d'Or Lakes was a series of lakes and river channels carved through the Carboniferous Windsor Group, soft sedimentary rocks comprised of limestones and evaporates (Shaw *et al.* 2002). However, the distribution of carbonate species and H_2S can be satisfactorily explained by the anaerobic process of dissimilatory sulphate reduction.

In the absence of oxygen, microbial respiration of particulate organic matter proceeds with a stepwise utilisation of alternative electron acceptors according to their energy yield *i.e.* NO_3^-, iron and manganese oxides, SO_4^{2-} and finally, carbon. Although there were no reliable nitrate measurements from the deep basin owing to the high levels of sulphide, the concentration is presumably very low owing to removal by the denitrification pathway which proceeds via nitrite, nitric oxide and nitrous oxide to nitrogen gas:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The reduction of particulate organic matter generally proceeds mainly through sulphate reduction owing to the relatively high abundance of SO_4^{2-} compared to other electron acceptors. The sulphate reduction of organic matter having a Redfield Ratio of 106C: 16N: 1P can be represented by the following general equation from Richards (1965):

$$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 53SO_4^{2-} \rightarrow$$
$$106HCO_3^- + 53H_2S + 16NH_3 + H_3PO_4$$

Hence, according to Hiscock and Millero (2006), the stoichiometric relationships between TA, TIC and H_2S can represented by the equations:

$$\frac{\Delta TA}{\Delta H_2S} \approx \left(\frac{106+16-2}{53}\right) = 2.3$$

$$\frac{\Delta TIC}{\Delta H_2S} \approx \left(\frac{106}{53}\right) = 2.0$$

$$\frac{\Delta TA}{\Delta TIC} \approx \left(\frac{106 + 16 - 2}{106}\right) = 1.13$$

For the Whycocomagh Bay anoxic zone, linear least square correlations for the measured parameters, with H_2S concentration corrected to gravimetric units of µmol kg^{-1} to match TIC and TA, shown above return slopes of 2.36 (R^2 = 0.85) for TA:H_2S, 2.05 (R^2 = 0.88) for TIC:H_2S and 1.15 (R^2 = 0.97) for TA:TIC, in excellent agreement with the theoretical relationships. Sulphate reduction can therefore largely explain the observed distribution of TIC and TA below the oxycline.

An interesting feature of the pCO_2 and pH time series is the increasing trend in pCO_2 at 20 m, from around 2,000 µatm in June to 5,491 µatm in December, with the development of a pronounced shoulder in the pCO_2 profile in October (Fig 4). The increase in pCO_2 was accompanied by a fall in pH to a minimum value for the year of 6.958 at 20 m depth in December (Fig 4). This is also the depth at which molecular oxygen first appears in the anaerobic/aerobic transition zone and the potential cause for this increase in pCO_2 is discussed later.

Dissolved methane, sulphide and ammonium

In the event that SO_4^- and the more energetically favourable electron acceptors become depleted, the reduction of organic carbon can only proceed by methanogenesis. The two perhaps most common pathways in the natural environment involve the reduction of carbon dioxide and acetate by methanogens, a group of obligate anaerobes belonging to the *Archaea* (Fenchel *et al.* 2012):

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Methane is of particular interest as it is a potent greenhouse gas with a global warming potential of about 80 times that of CO_2 over a 20 year time frame (Myhre *et al.* 2013). Shelf seas and estuaries hold a disproportionate importance in the global sea/air flux and it has been estimated that these regions, accounting for only about 16% of the global ocean area, may contribute 75% of total marine CH_4 emissions (Weber *et al.* 2019, Rosentreter *et al.* 2021).

Surface CH_4 concentrations were in the range 19-35 nmol L^{-1} (727-1,147% saturation) and a curious sub-surface maximum was observed in the October and December profiles (Fig 5b). The source

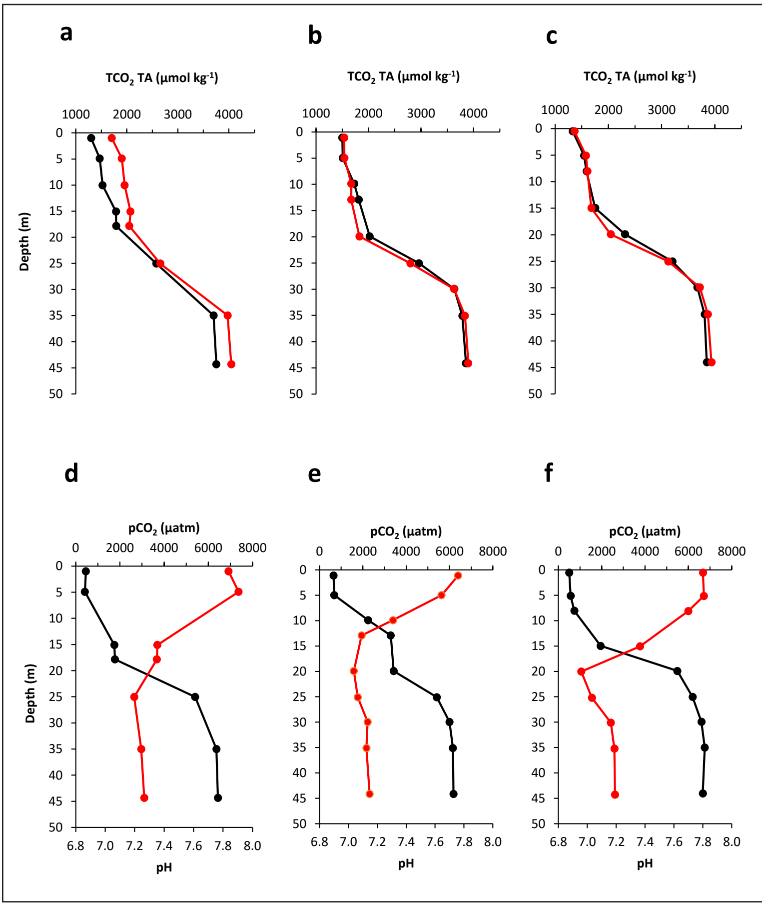

Fig 4 The top row shows profiles of total dissolved inorganic carbon (black) and total alkalinity (red) in the Whycocomagh Basin on June (a), October (b) and December (c), 2017. The bottom row shows profiles of pCO_2 (black) and pH (red) on June (d), October (e) and December (f).

of this maximum is not clear, and they coincide approximately with the sub-surface temperature inversions (Fig 2b & 2c). In order to assess the fresh water source of methane, the mouth of the Skye River was sampled and had a concentration of 57.4 nmol L^{-1} (1,658% saturation), hence riverine CH_4 input contributes to CH_4 super-saturation in the surface water of Whycocomagh Bay.

Dissolved methane concentrations in the deep anoxic water were astonishingly high, approaching one million percent saturation (range: 31.40-34.74 µmol L^{-1}, 844,896-931,909% saturation).

These concentrations are a factor of 10 higher than those seen in the permanently anoxic marine waters of the Black Sea and Cariaco Basin (Kessler and Rheeburg 2006), although still below the highest levels measured in deep freshwater lakes (e.g. Blees *et al*. 2014). Above 30 m, the concentration declined steeply by a factor of 1,000 (Fig 5). Processes responsible for this pattern may include diapycnal transport driven by the CH_4 concentration gradient with subsequent advection and release to the atmosphere, and microbial oxidation (MOx) by methanotrophic bacteria.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

In this study, the CH_4 concentration gradients lie rather lower than the pycnocline and seem to be more associated with the depth where molecular oxygen first makes an appearance. This is consistent with removal by methanotrophy, as the study of Steinle *et al*. (2017) showed that MOx rates in the western Baltic Sea were optimal at sub micro-molar O_2 concentrations.

Potential rate of methane oxidation

On the final visit to Whycocomagh Bay in December, water was sampled for an incubation experiment to investigate the rate of microbial methane oxidation at the base of the oxycline.

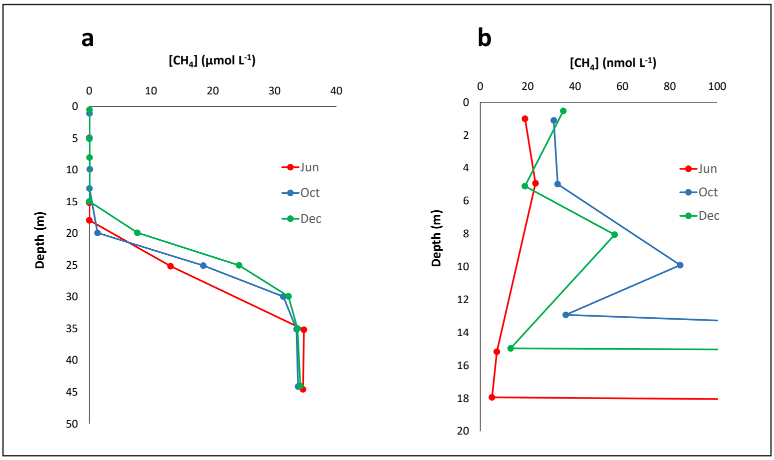

Fig 5 **(a) Dissolved methane concentrations (µmol L^{-1}) in the Whycocomagh Basin in June, October and December 2017. (b) Surface concentrations of methane (note the unit: nmol L^{-1}).**

Repeated casts to the 16-18m depth range were made with a 5 L Niskin bottle and the water transferred to an acid rinsed 20 L glass carboy. Some degree of gas exchange between the water and atmosphere was inevitable during the transfer process, hence the oxygen concentration *in vitro*, later determined to be 109 µmol L^{-1}, was almost certainly higher that the *in situ* concentration, and so the measured rate should be regarded as a potential one (i.e. not limited by oxygen availability). The carboy was transported to the laboratory and the water subdivided by siphoning into sixteen, 125 mL serum bottles, half of which were poisoned by the addition of mercuric chloride. The bottles were incubated in the dark at *in situ* temperature, and a pair of poisoned and non-poisoned samples were analysed for dissolved methane at intervals. The non-poisoned time series showed a linear decline in methane concentration of around 50% over the initial 24 hours, a loss rate of 0.34 µmol L^{-1} d^{-1} (Fig 6). This value is much higher than that measured in a coastal inlet in the south-western Baltic Sea using the similar method, ranged from 1.0-11.6 nmol L^{-1} d^{-1} (Steinle *et al.* 2017). However, multiple environmental factors can affect the methane oxidation rate,

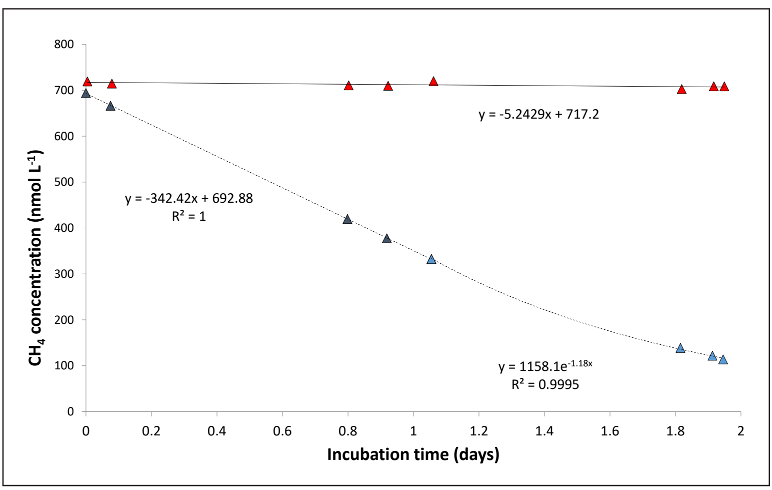

Fig 6 A two day series of incubation measurements of methane subsamples drawn from a bulk water sample collected from the base of the oxycline at Site 1 in the Whycocomagh Basin on the 5th of December, 2017. Red triangles represent poisoned subsamples, blue triangles show non-poisoned samples. A linear regression was fitted to the entire poisoned data set, and to the initial 24 hours of non-poisoned data, whereas the subsequent measurements were best represented by an exponential fit.

including oxygen concentrations and water temperature, therefore the direct comparison requires caution. Measurements in the second day of incubation indicate that methane removal had entered a non-linear phase, with an exponential regression offering the best fit. This transition from zero order (independent of substrate concentration) to first order (concentration-dependent) kinetics may reflect the substrate handling capacity of the bacterial population.

The emerging picture of methane dynamics in Whycocomagh Bay is one of intense microbial oxidation activity in the hypoxic zone that potentially acts as a filter to limit the transfer of methane into the surface mixed layer and thus mitigate atmospheric release (Steinle *et al*. 2017). This process may explain the persistent pCO_2 sub-surface maximum at around 20 m depth observed through the year, a result of the conversion of dissolved methane to carbon dioxide. This model also raises the question of the degree to which this form of chemolithotrophic primary production in the water column, independent of light availability, can support higher trophic levels, analogous to cold seep biomes.

Sulphide and ammonium are the terminal products of sulphate and nitrate reduction. In the absence of a suitable electron acceptor, H_2S and NH_4^+ will accumulate in stagnant anoxic environments, but unlike methane, they are toxic in high concentrations to vertebrates and invertebrates, and may have a detrimental effect on aquaculture operations and fisheries. The seasonal distributions of sulphide and ammonium are shown in Fig 7.

H_2S was always undetectable in the well oxygenated surface water, yet abundant in the hypoxic or anoxic water present below around 20 m depth in the central basin. In the bottom water (44 m), sulphide concentration increased during the course of the year from 734 µmol L^{-1} in June to 841 µmol L^{-1} in October and on to 1,047 µmol L^{-1} in December. This increase is likely related to an annual cycle in organic matter input in which case, in order to maintain a quasi-steady state from year to year, the 70% increase in sulphide from June to December would have to be balanced by a net loss during the winter months. Physical loss processes include diffusion across the oxycline where H_2S undergoes spontaneous chemical oxidation in oxygenated seawater, a first order reaction with a H_2S half-life of around one day (Zhang and Millero 1993). H_2S may also be consumed in the absence of oxygen by photosynthetic purple

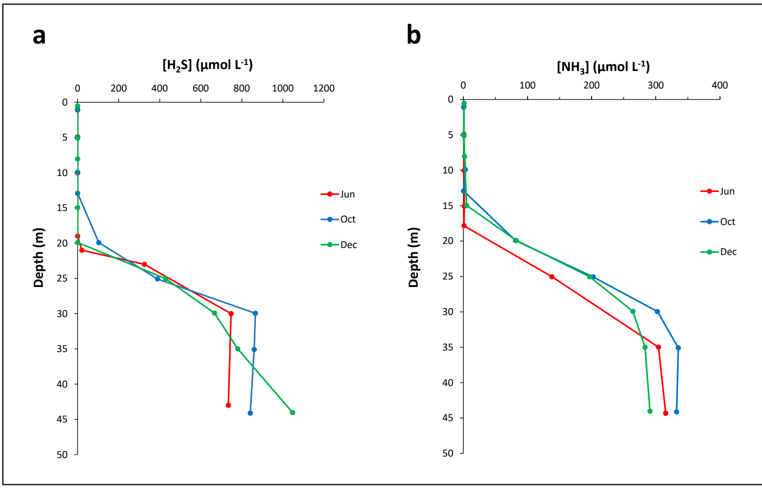

Fig 7 Profiles of (a) total sulphide (H_2S), and (b) ammonia concentrations in the Whycocomagh Basin in June, October and December 2017 (Dates as in Fig 3).

sulphur bacteria, and in the presence of oxygen by sulphur oxidising bacteria such as *Beggiatoa* (Jørgensen *et al*. 2010). The significance of these microbial pathways at this site is not yet known, but imaging with a drop camera and ROV shows a distinct pseudo benthos (Siebrth 1987, Ott and Herndl, 1992) at 16.5 m depth in the water column, and a dense band of *Beggiatoa* on the seabed perimeter of the Whycocomagh basin between 15 and 19m depth. (Hatcher, unpublished data).

The distribution of ammonium (NH_4^+) was similar to that of dissolved methane, with high concentrations below 30 m and low concentrations in the upper 15 m of the water column (Fig 7). Bottom water values remained fairly stable, fluctuating between 315.5 µmol L^{-1} in June, 332.5 µmol L^{-1} in October and 291.0 µmol L^{-1} in December. Unsurprisingly, surface water values were much lower given that ammonium is a preferred source of nitrogen for phytoplankton, ranging from 0.4 to 1.1 µmol L^{-1}. In anoxic marine environments, ammonium is produced by the bacterial process of ammonification, i.e. the microbial deamination of organic matter where ammonium is a metabolic product. A further source of ammonium is dissimilatory nitrate reduction to ammonium, with nitrate as an electron acceptor. The latter pathway is often coupled across the anaerobic/aerobic interface with the oxidation of ammonium to nitrite, i.e. the first stage of nitrification where nitrous oxide is released as a by-product (Pajares and Ramos 2019). Although nitrous oxide concentrations were not measured in the study, it is highly likely that Whycocomagh Bay is a strong source of this powerful greenhouse gas.

A comparison of these data with 1996-1997 measurements of sulphide and ammonium reveals a striking contrast. Strain *et al.* (2001) reported deep water values in Whycocomagh Bay of 30-62 µmol L^{-1} H_2S and 66-136 µmol L^{-1} NH_4^+. The subsequent, twenty year interval has therefore seen more than a tenfold increase in sulphide and around a threefold increase in ammonium, suggesting a trend of increasing eutrophication.

Phosphate and silicate

Distributions of phosphate and silicate for 2017 are shown in Fig 8. In both cases there was a shoaling of the nutricline as the year progressed. The bottom water phosphate concentration was relatively stable throughout 2017, remaining between 36.1-37.6 µmol L^{-1}. Organic phosphate contained in particulate organic matter will be regenerated during dissimilatory sulphate reduction. A plot of H_3PO_4 vs TIC in anoxic water had a slope of 0.015, i.e. a C:P ratio of 106:1.6, which is rather higher than the standard Redfield Ratio given in Eqn. 2. This may reflect the influence of terrestrial runoff or a higher C:P ratio in anthropogenic discharges compared to particulate organic matter resulting from *in situ* photosynthesis.

Bottom water silicate concentration also varied slightly, ranging from 154.9 to 162.3 µmol L^{-1} (Fig 8) and the profile also showed a classic pattern of surface uptake and deep water regeneration. The source of silicate to the Bras d'Or Lakes is likely to be primarily through rock weathering and freshwater runoff, while deep water enrichment can be caused by the transfer of silica in sinking diatoms, although one cannot rule out accelerated dissolution of silicic sediments in the low pH anoxic zone. Redfield stoichiometry for diatoms has been expanded to include silica with a mean Si:C ratio of 0.13 being reported for a range of cultures (Brzezinski 1985). These results yield a Si:C ratio of 0.062 in anoxic water, which is consistent with some fraction of the total organic matter supplied to the deep basin being comprised of diatoms.

In the 1995-1997 study of Whycocomagh Bay, the deep water concentrations were 9.2-14.0 µmol L^{-1} for H_3PO_4 and 37-85 µmol L^{-1}

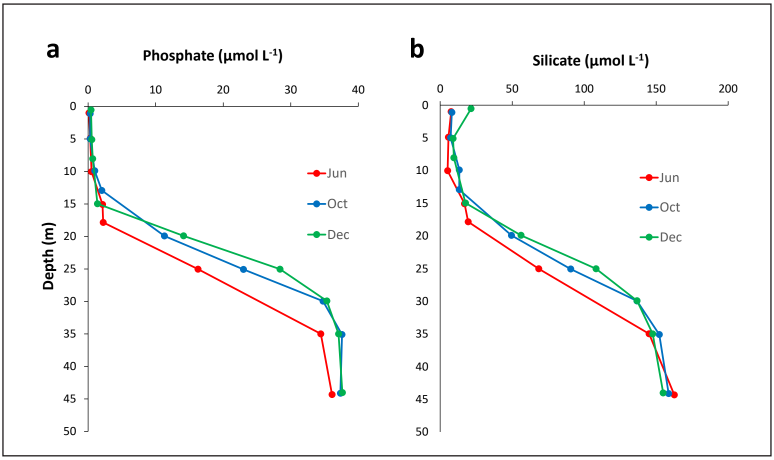

Fig 8 **Profiles of a) phosphate and b) silicate concentration through the water column measured at Site 1 in the Whycocomagh Basin in June (red), October (blue) and December (green). (dates as in Fig 3).**

for $Si(OH)_4$ (Strain *et al*. 2001). These more recent measurements show at least a two fold increase for these nutrients, again suggesting ongoing eutrophication.

Summary of biogeochemical processes

Fig 9 illustrates a simple model of the major biogeochemical pathways relevant to the compounds measured in this study. Particulate organic carbon comprised of marine and terrestrial organic matter sinks down to the water/sediment interface. Anaerobic decomposition and remineralisation proceeds largely by sulphate reduction, with the release of bicarbonate, hydrogen sulphide, ammonium, phosphate and silicate, while methanogenesis releases both methane and carbon dioxide to the water column. These products diffuse into the hypoxic layer between around 15 to 20 m depth where ammonium, hydrogen sulphide and methane are vigorously oxidised, the upward flux of these compound being balanced by a downward flux of molecular oxygen. Hydrogen sulphide is completely removed in this layer, being absent in the oxygenated surface water. The remaining gases and nutrients escape to a greater or lesser degree into the surface layer and provide the requirements for photosynthesis while supersaturated levels of methane and carbon dioxide drive a sea to air flux of these gases.

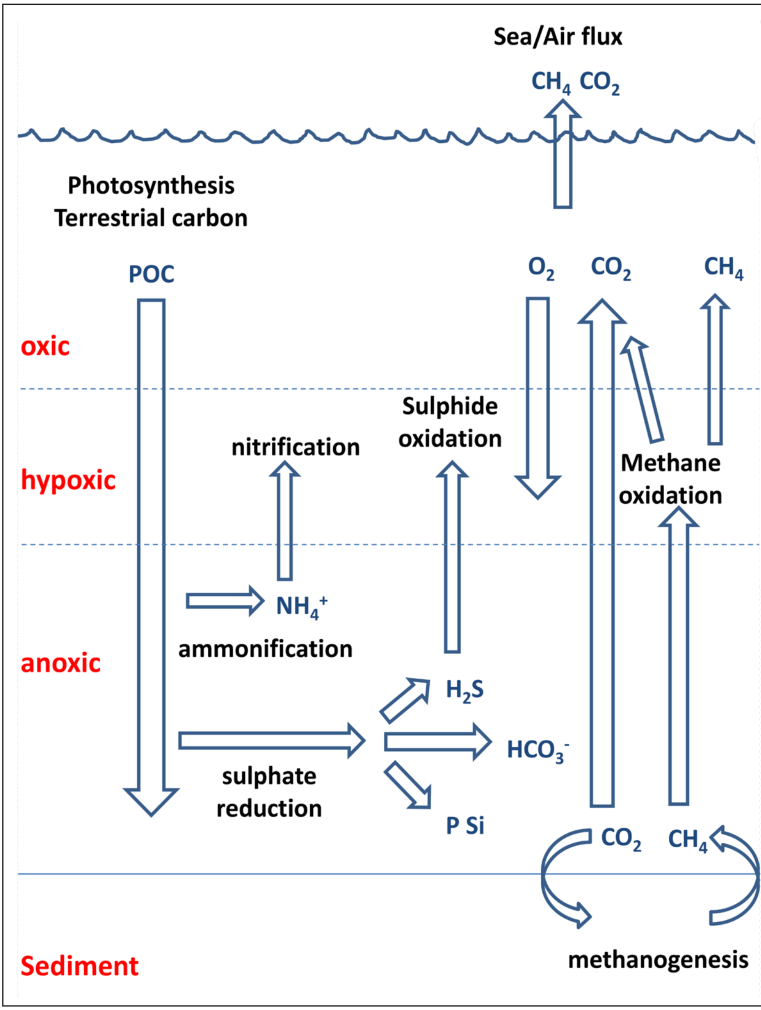

Fig 9 **A simplified diagram of the major relevant biogeochemical pathways in the Whycocomagh Basin, Bras d'Or Lake, Nova Scotia.**

CONCLUSIONS

The basin in Whycocomagh Bay, Bras d'Or Lakes, with a likely state of permanent anoxia in the deep water, provides a unique and easily accessible site where elemental redox processes can be conveniently studied. The hypoxic/anoxic cycling of organic carbon is of particular interest. Distributions of the dissolved carbon dioxide parameters TIC and TA in the anoxic zone can be explained by sulphate reduction of particulate organic matter with a Redfield C:N:P ratio of 106:16:1.6. Although the concentration of dissolved methane accumulating as a result of contemporary methanogenesis is among the highest recorded in a marine basin, the very high potential rate of microbial methane oxidation at the base of the oxycline suggests that this is substantially mitigating the atmospheric release of CH_4. This hypothesis is supported by a co-occurring pCO_2 maximum in the hypoxic zone. It would be worth making further, fine scale measurements of MOx rate through the well-defined oxycline to investigate its dependence on substrate concentrations. Also, it would be of interest to find out if this chemolithotrophic activity is supporting higher trophic levels through the grazing of methanotrophic bacteria by microzooplankton.

A comparison with sulphide and nutrient data obtained here two decades ago show a tenfold increase in H_2S, a threefold increase in ammonium and a doubling in phosphate concentration in the stagnant deep water. This is strong evidence of eutrophication, presumably resulting from, or enhanced by, anthropogenic sources of particulate organic matter from nearby sewage discharges and from aquaculture operations in the bay. In this regard, the chemical conditions pertaining to Whycocomagh Bay may be an analogue for larger perturbed estuaries.

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SYDNEY HARBOUR: SEICHES, TIDES AND MEAN CIRCULATION

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ABSTRACT

Beginning with observations from 1901, sea level elevations and currents from Sydney Harbour are examined across a broad frequency range. The mean currents, annual components of sea level, tides and seiches, mainly in the South Arm, are the focus. Tidal and mean currents are ~0.01 m s^{-1}. The general circulation is estuarine-like with a thin, near-surface outflow layer and a thicker, deeper inflow. The distribution of contaminants in bottom sediments suggests the circulation, though weak, plays a retentive role in the Arm, transporting sediments towards its head. Analysis of 11-years of sea level data indicates a strong annual cycle, more energetic during winter than from late spring to early fall. The increased energy occurred at all frequencies except for tides. Seiches, with periods of ~0.5 to 2 h, emerge as a strong contributor to sea level and currents. The distributions of elevation and flow amplitudes associated with seiches were derived. With maximum observed values of 0.74 m and 0.24 m s^{-1}, seiche displacements and currents can exceed those associated with tides and the mean circulation. While earlier studies identified only the dominant fundamental seiche mode, recent sea level data sampled at 1-minute show that modes 2-4 occur.

Keywords: Sydney Harbour, sea level, mean circulation, tides, seiches

INTRODUCTION

Sydney Harbour situated in eastern Cape Breton, Nova Scotia, opens onto Sydney Bight, the area of ocean bordered by Cabot Strait, Laurentian Channel and the eastern Scotian Shelf. The Harbour is 'Y' shaped with the seaward arm dividing into a Northwest and South Arm (Fig 1A, B). The South Arm is about 10 km long, 1 km wide and 10 m deep. Sydney River empties into the Harbour at its head and has an estimated peak monthly inflow of about 21 m^3 s^{-1} in April and a minimum inflow of about 5 m^3 s^{-1} in July and August (Gregory *et al.* 1993). At the annual average rate of 10.4 m^3 s^{-1},

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the freshwater inflow would take ~116 days to fill the South Arm. The South Arm of the Harbour is the focus of this study.

Several physical oceanographic studies have been carried out in Sydney Harbour over the past century. W. Bell Dawson, Superintendent of the Tidal and Current Survey of Canada, initiated a comprehensive program to establish reference benchmarks and collect sea level data for the Gulf of St. Lawrence and Atlantic Canadian ports, including Sydney, in the late 1800s (Dawson 1917; see Appendix, Fig A1). Dawson (1917) reported extreme low and high-water levels from continuously recording gauges placed in the Harbour at Battery Point in 1901 (July) and 1915 (July-October; see Fig 1A for location). Honda and Dawson (1911) analyzed the 1901 records for oscillations due to seiches, harmonic motions related to the

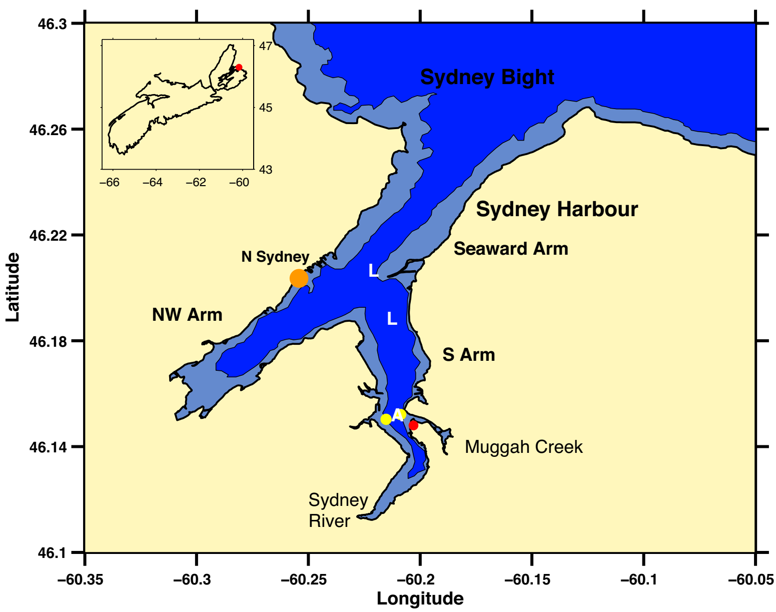

Fig 1A **Map of Sydney Harbour opening onto the Sydney Bight to the northeast. The locations of the long-term tide gauge at North Sydney (large orange dot) and Sydney River, the main source of freshwater to the Harbour are indicated. The letters indicate the locations of current meter moorings by Lane (L; 1989, 1991) and ASA (A; 1994; off Muggah Creek); the 2 yellow dots, the sites of the Fisheries and Oceans ADCPs, 2000-2001 (off Muggah Creek). The red dot at the mouth of Muggah Creek marks Battery Point, the site of Dawson's tide gauge. Depths greater (shallower) than 10 m are shown in dark (light) blue. The inset shows the location of Sydney Harbour (red dot) relative to Nova Scotia.**

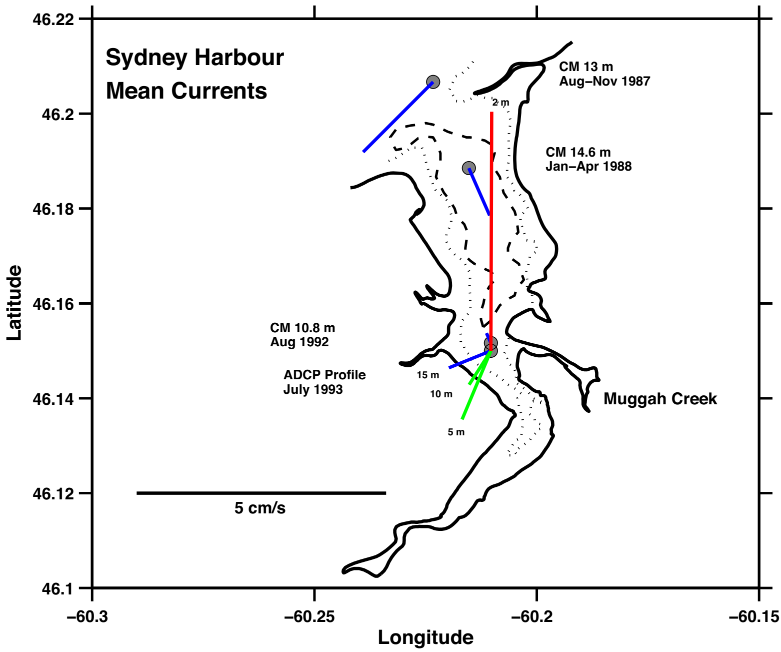

Fig 1B **Bathymetry of the South Arm of Sydney Harbour showing the 10 m (dotted line) and 15 m isobaths (dashed line). Mean current vectors from the Lane and ASA moorings are shown. Blue, green and red vectors depict the current for depths > 10 m, 5-10 m and <5 m. CM refers to single depth instruments. The current scale is indicated in the lower left of the figure.**

geometry of an inlet. These resonances can limit the usefulness of many harbours and are generally most prominent as the fundamental mode (Miles and Munk, 1961). The period of the fundamental mode of a harbour of length L and depth z_0 is given by Merian's formula as $4L/(gz_0)^{1/2}$, where g is the acceleration due to gravity. Honda and Dawson (1911) calculated two dominant seiche periods of 120 and 132 minutes based on the dimensions of the Harbour from the mouth to the head of the Northwest and South Arms, respectively, and by assuming that the oscillations were generated independently in each arm. Easton (1972) refined the calculations of Honda and Dawson (1911) by constructing an analytical solution for a three-channel model of the Harbour with seaward, south and northwest arms. In addition, he developed a cross-sectionally averaged numerical model of the inlet. Easton (1972) reported a period of 124 minutes for the fundamental mode, close to the results of Honda and

Dawson (1911); he identified 3 additional, higher frequency modes. Some additional notes on these models are given in the Appendix.

Lane (1989, 1991) and ASA (1994) conducted environmental studies primarily in the South Arm. While the programs focused on pollutants in Harbour waters, in situ observations of currents (moored instruments, locations shown in Fig 1), temperature and salinity complemented the chemical sampling. The ASA (1994) program was related to the feasibility of developing a sewage treatment plant with effluent flowing into the Harbour. Supporting data included moored current meters (location shown in Fig 1, one single point instrument, 1 acoustic Doppler current profiler (ADCP) sampling at 1 m resolution from ~2 to 14 m, bottom depth 15 m), transects with ship-borne acoustic Doppler current profilers and hydrographic sampling (temperature and salinity). The currents derived from these moorings feature outflow from the South Arm concentrated in the near-surface (~0-2.5 m) with a deeper, more extensive inflow towards Sydney River (Fig 1B). Some of these data were used by Petrie *et al.* (2001) in a review of limited aspects of the physical oceanography of Sydney Harbour.

The Canadian Hydrographic Service (CHS) has maintained a sea level gauge at North Sydney since 1970 (Fig 1A).

DATA AND METHODS

The sea level record shown in Honda and Dawson (1911) was digitized at 30-minute intervals then filtered (high-pass Butterworth filter, 4-hour cutoff) to focus on the high frequency seiche oscillations.

North Sydney sea level data were obtained from the Marine Environmental Data Service, Fisheries and Oceans Canada (MEDS, Ottawa, Canada http://www.isdm-gdsi.gc.ca/isdm-gdsi/index-end.html). The observations from 1989 to 1999 had a nominal sampling interval of 15 minutes which allows for the resolution of the high frequency seiches and longer period motions. During the period 1989-1999, the ~337,000 observations represent an 87.3% data return. Honda and Dawson (1917) and Easton (1994) reported only observing the fundamental seiche mode, with a period of ~2 h; this mode would be well-resolved in records with 15 minute sampling. The 15 minute sampling also can resolve the shorter period seiches indicated by Easton (1972).

Current meter and hydrographic observations were extracted from the Bedford Institute of Oceanography database (https://www.bio.gc.ca/science/data-donnees/base/index-en.php). The current meter data from the studies of Lane (1989) and ASA (1994) in the South Arm (Fig 1A) are particularly useful because their sampling interval of 15 minutes allows for the resolution of flows with periods longer than 30 minutes. The 2 single point current meter records from Lane (1989) were from just outside (13 m, bottom depth 14 m; 24 August-13 October 1987) and just inside the South Arm (14.6 m, bottom depth 16 m; 12 January-27 April 1988). ASA (1994) reports data for a single point current meter (10 m, bottom depth 16 m; 6 August-2 September 1992) and an ADCP (bottom-mounted, depth 15 m; 25 July-24 August 1993). These records are confined mostly to late summer-early fall, so an annual cycle of currents cannot be established. In October 2000, Fisheries and Oceans Canada (DFO) placed 2 ADCPs in the South Arm one (46.1521 °N, 60.2087 °W, bottom depth 14 m) just off the northern side of the mouth of Muggah Creek, the second (46.1503 °N, 60.2152 °W, bottom depth 12 m) 544 m to the WSW, off the western side of the Arm. Both moorings were recovered in May 2001, providing 216 days of observations sampled hourly. These records have not been reported elsewhere.

Amplitudes and phases were estimated from the datasets using harmonic analysis. Typically, the expression $A0 + A1*\cos(\omega(t-\varphi))$ was used in a least-squares fit where A0 is a constant (average value), A1 is the amplitude of the harmonic which has a frequency ω (=2*π/period), t is time and φ is the phase. Both Butterworth high pass (cutoff at 4 h) and Loess filters were used to examine the low or high frequency components of the datasets. Power spectra (distribution of data variance with frequency) were estimated using the routine pwelch in Matlab.

RESULTS

Overall sea level and current variance

The overall variances of the sea level and current meter records are the result of many forcing mechanisms, including the flows driven by freshwater inflow (periods of days to annual cycles), long period tides and circulation changes outside the Harbour (solar annual tidal constituent, annual water mass variations in Sydney Bight), meteorological forcing (wind stress, atmospheric pressure; periods of days to a year), tides (for Sydney Harbour the semi-diurnal {~twice per day} and diurnal {~once per day} tides are the most energetic), and the higher frequency seiches as noted by Honda and Dawson (1917) and Easton (1972).

The annual cycle of sea level variance by month was determined from the 1989-1999, 15-minute time series. Monthly values of variance were calculated for each year and then averaged across all years. It includes variability for periods ≥ 30 minutes and is a comprehensive estimate of the annual cycle of variance. The estimates, which lie between ~0.092 m^2 (May-September; equivalent to an amplitude of 0.43 m) and 0.114 m^2 (January; 0.48 m), show a distinct annual variation, high during winter, low from late spring to early fall (Fig 2A). The greater part of the variance is due to the daily and twice daily tidal components. In fact, the variance of the five leading tidal constituents, M2, S2, N2, K1 and O1, alone is 0.083 m^2, or 90% of the base variance of 0.092 m^2. However, their contribution to the overall variance would be nearly constant every month, i.e., they would not contribute to the month-to-month variation (≡excess variance) seen in Fig 2A. Harmonic analysis shows that the excess variance is dominated by an annual cycle with an amplitude of 0.011 m^2 and a phase of 0.73 months (peak ~ Jan 23); it accounts for 88% of the variation. Potential sources of energy are wind-driven currents and their associated surface displacements; storms tend to be more numerous and stronger in winter than during summer. In addition, atmospheric pressure, generally lower during winter than in summer, could contribute. Based on the latest 30-y barometric pressure climatology for Sydney, the variance of this component is only 0.00015 m^2, and therefore relatively insignificant. At higher frequencies, seiches generated by the wind could also contribute.

Low-frequency contributions to variance

A potential contributor to the annual cycle of sea level variance is the long period tides, notably the solar annual component (SA, period 365.24 days). In fact, the CHS reports a relatively large solar annual tidal constituent of 0.07 m with a peak amplitude in early December for North Sydney based on a 1-year record. However, if this were a pure tidal harmonic, its contribution to

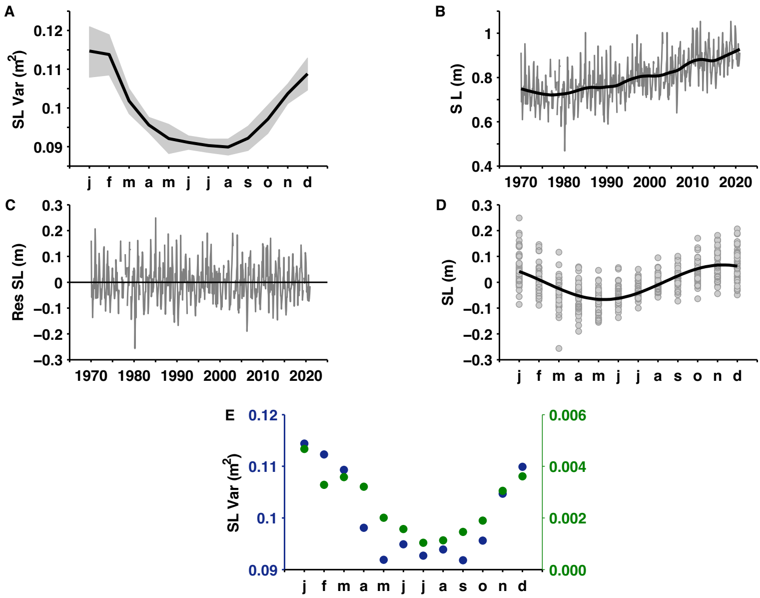

Fig 2 **A) Annual cycle of sea level variance (SL Var, black line) and 95% confidence limits (grey shading) for Sydney Harbour based on North Sydney observations (1989-1999; 15 minute sampling). B) Monthly sea levels (SL, grey line) and long-term mean sea level variation (linear Loess 0.1 filter of monthly values, black line) 1970-2020 at North Sydney. C) Monthly sea levels with long-term variation removed. D) Annual harmonic of sea level (black line) based on the monthly observed values (grey points, 1970-2020; Fig 2C). E) Annual cycle of sea level variance (blue points) calculated from record sampled at 15-minute intervals; annual cycle of sea level variance from the monthly sampled record (green points).**

the monthly variance would have a frequency 2 times the annual; its largest impact to would occur at 3 and 9 months after the solar annual peak when the rate of change of the elevation associated with the annual harmonic is greatest; thus, it would be out of phase with the annual cycle of variance. Moreover, with an amplitude of 0.07 m, the largest contribution is only about 5% of the excess variance. Other factors such as changes in the water temperature and salinity and hence density, and annual variation of the current exterior to the Harbour can affect the annual cycle of sea level and emerge as a solar annual component in a short term (~1 year) tidal analysis. Annual cycles of temperature, salinity and circulation have been observed (Petrie and Drinkwater 1993, Drinkwater *et al.* 1979). This component of sea level can be examined by calculating the monthly averaged sea levels (Fig 2B). The monthly averages effectively filter out the high frequency contributions to sea level including the dominant diurnal and semidiurnal tides, seiches and other short period variability.

The inter-annual variations of the annual cycle of monthly sea level are readily apparent along with a trend of increasing sea level (Fig 2B). Removing the trend (linear Loess 0.1 filter) shows the month-to-month variability more clearly (Fig 2C). Grouping the values by month reveals a distinct annual cycle (Fig 2D). Harmonic analysis gives an annual cycle with an amplitude of 0.067 m and a peak in early December, about 4 days later than the CHS result. The agreement is surprisingly good given the CHS result was based on a 362 day hourly record, whereas this analysis is based on a 5-decade series of monthly values. Note the greater scatter, i.e. increased variance, about the annual harmonic during the late fall-winter months than during the summer. The monthly variances (Fig 2D) are compared to the excess variance in Fig 2E. Although the patterns of both series – high in winter, low in summer – match well, the inter-annual variability of the annual cycle only accounts for about 13% of the excess variance. Steps to assess the contribution of inter-annual variability of the annual cycle are summarized in the Appendix.

The trend of increasing relative sea level at North Sydney is 39.1 cm/century (Hebert *et al.* 2021, see Fig 2B); where relative sea level refers to water level relative to a fixed benchmark on land). This is similar to trends of 37.5 cm/century for Yarmouth and 33.3 cm/century for Halifax. When corrected for post-glacial rebound (the crustal response to the retreat of the ice sheet; for all 3 sites, the crust is sinking), the trends are 27.2, 18.6 and 22.3 cm/century for Yarmouth, Halifax and North Sydney, respectively (Hebert *et al.* 2021). However, the trend for Halifax was based on the 1920-2020 data series, about 50 years longer than those for Yarmouth (1967-2020) and North Sydney (1970-2020). Using the 1970-2020 Halifax record, the relative sea level trend is 32.7 cm/century, 0.6 cm/century lower than the 1920-2020 trend. Hebert *et al.* (2021) do not offer an explanation for the different trends among the 3 sites.

Variance during summer versus winter

The contributions to the variance over a broad range of frequencies can be investigated by comparing the winter and summer sea level spectra. For 1989-1999, spectra could be computed for records of January-February-March (winter) sea level for 1990, 1991, 1993 and 1995, and for July-August-September (summer) for 1991-1994 and 1999. The average winter spectrum is generally greater across all frequencies than the average summer spectrum (Figs 3A,B). Several features emerge: the greatest increases of variance occur at frequencies of 0.2 to 1 cpd (cycles per day; Fig 3B).

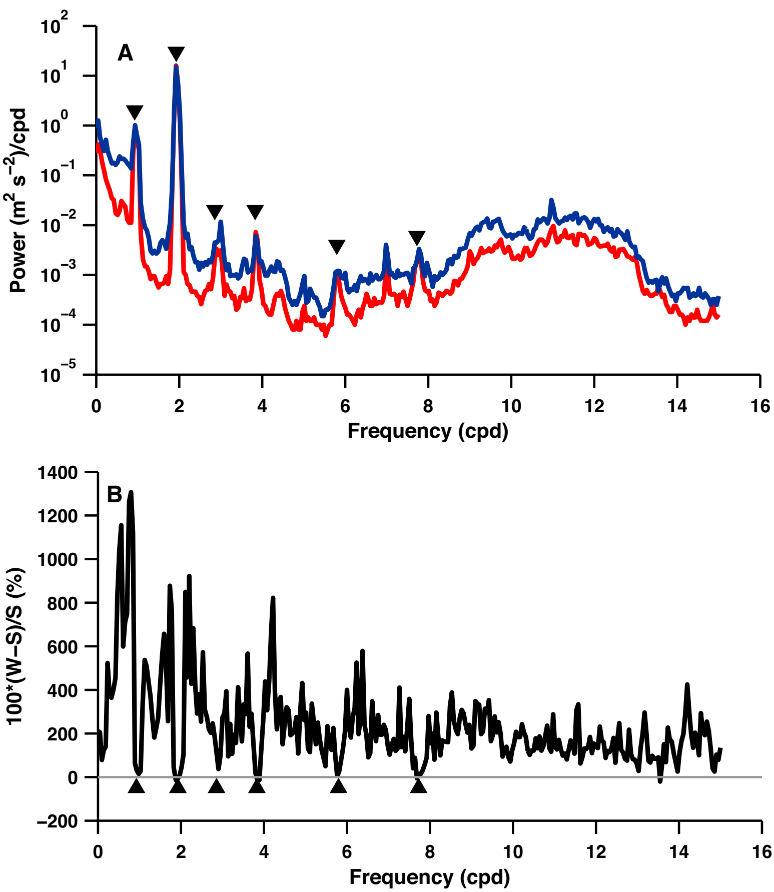

Fig 3 **A) Average sea level winter (summer) spectrum (January-February-March, blue; July-August-September, red) derived from 15 minute observations at North Sydney. Spectra cover frequencies from 0.047 to 48 cpd; frequencies higher than 15 cpd had little energy and are not shown. B) Percentage difference of winter spectrum relative to the summer spectrum. In both panels, triangles indicate frequencies of tidal constituents at approximately 1, 2, 3, 4, 6 and 8 cpd.**

Integration over this band yields an equivalent amplitude of 0.058 m for summer and 0.144 m for winter. These values differ significantly at the 95% confidence level. The largest contributions by far to the overall variance are from the semi-diurnal and diurnal tides; on the other hand, the summer-to-winter differences at tidal frequencies, approximately 1, 2, 3, 4 , 6 and 8 cpd (cycles per day; periods of 24, 12, 8, 6, 4 and 3 h), are close to 0, which is expected (Fig 2B). The appearance of tidal harmonics, constituents caused by non-linear effects, near 3, 4, 6 and 8 cpd, is novel given the low tidal velocities. Integrating across the spectral peaks near these frequencies gives amplitudes of 13, 0.8, 0.5 and 0.8 mm; this compares favourably with the CHS tidal constituents of 3.5 mm average value of 7 constituents at ~3 cpd, 4 mm for 4 constituents at ~4 cpd, 2.2 mm for 2 at ~6 cpd, and 2.6 for 4 constituents at 8 cpd (analysis from P. MacAulay, CHS, Bedford Institute of Oceanography).

In summary, the increased sea level variance during the winter compared to summer appears due to a general rise across all frequencies with the exception of the tides. Greater increases of variance are found in the storm band (frequencies 0.2-1 cpd). The winter to summer difference in variance (0.0193 m^2 s^{-2}, Fig 2A) matches the difference (0.0188 m^2 s^{-2}) calculated by combining the integrals over the spectra (Fig 3A) and the variance due to the annual cycle (Fig 2E).

Seiches

Honda and Dawson (1911) show only 21 hours of observations of the month-long sea level record of 1901 at Battery Point. A digitized, high-pass filtered time series of their Plate 1 (Fig 4A) shows seiche amplitudes as large as ~0.2 m with an average period of ~125 minutes, agreeing well with their estimated period of 132 minutes for the South Arm (note that the average depth stated by Honda and Dawson (1911) for the Harbour was 4.1 m, likely an error as the average depth is ~10 m; moreover, using their stated depth, the fundamental periods would be 179 and 197 minutes, considerably longer than the 120 and 132 minutes they reported).

Easton (1972) calculated resonant periods of 103, 52, 36.6 and 22.5 minutes for the first four modes of his three-channel model of the Harbour. The depth and width of each channel was constant but differed among the three. He refined this idealized model by incorporating variations in depth and cross-section; he solved the finite difference forms of the governing equations, obtaining resonant periods

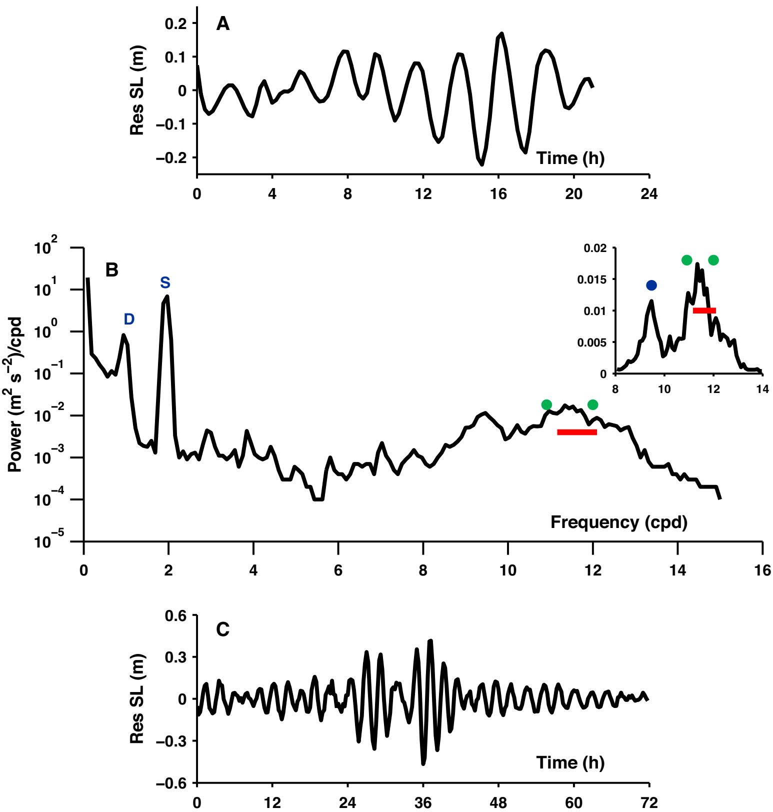

Fig 4 **A) High-passed (cutoff at 6 cpd) sea level record from Honda and Dawson (1911). From hour 8 to 20.5 there are ~6 cycles which gives an average frequency of 11.5 cpd. B) Spectrum of North Sydney sea level observations (January 27-June 27, 1990; 15-minute sampling interval). The dominant diurnal (D) and semi-diurnal (S) peaks are evident; in addition, a broad spectral peak encompassing the seiche fundamental mode is indicated (green dots are the 2 fundamental periods calculated by Honda and Dawson (1911), the red line represents the seiche frequency band predicted by Easton (1972)). The inset magnifies the structure in the seiche band and shows an estimated, typical edge wave frequency (blue dot) predicted by Easton (1972). C) Highest sea level seiche amplitude burst for the period January 27-June 27, 1990 occurred from February 24-27, where hour 0 corresponds to 00:00 February 24.**

of 107, 39, 31.5 and 24 minutes at mean water level, different from the periods based on the 3-channel model. Repeating the calculations for high and low tidal elevations modulated the period of the first mode by a range of 10 minutes. Further, a correction for the Harbour opening onto the ocean increased its period from 107 to 124 minutes.

Easton presented only 12 h of the 1970 sea level records from North Sydney he analyzed; his Fig 1 shows a distinct seiche with a peak amplitude of ~0.28 m and a period of ~123 minutes. He reported distinct oscillations with periods in a narrow band of 120 to 130 minutes lasting for 12 hours to 3 days and amplitudes as large as 0.6 m. This corresponds to an average current at the mouth of the Harbour of ~0.25 m s^{-1} (=2*0.6 m*54.4*10^6 m^2/(73*10^3 m^2*3600 s), where 54.4*10^6 is the surface area of the Harbour, 73*10^3 is the cross-sectional area at the mouth of the Harbour). Easton (1972) concluded that the seiches were initiated by storms and were probably the response to external edge waves, whose periods he estimated as about 152 minutes. External edge waves, generated by passing atmospheric disturbances, are natural, oscillatory motions over a sloping bottom at the coast. Their crests are normal to the shoreline and travel in a direction parallel to the shore. Wave amplitudes diminish rapidly with offshore distance (within ~10 km).

The amplitude structure of the fundamental seiche mode from Easton's model indicates that the highest sea level elevations are found at Sydney River, the head of the South Arm. Relative to a peak magnitude of 1 at the head of the South Arm, the amplitude decreases to 0.93 at Battery Point where Dawson's observations were taken, and to 0.79 at the mouth of the Arm. At the site of the CHS gauge at North Sydney, the amplitude further decreases to 0.74. This suggests that the seiche amplitudes in the South Arm might be as much as 35% higher at its head and 26% higher at Battery Point than those recorded by the CHS gauge.

To examine further the predictions of Honda and Dawson (1911) and Easton (1972), sea level data were obtained from MEDS. Data are available at sampling intervals of 1 and 15-minutes, 1-hour, and 1-day depending on the year. However, only hourly and daily formats, sampling frequencies inadequate to resolve the seiche periods, were available for the 1970 data examined by Easton (1972). Instead, a 5-month long series sampled at 15-minute intervals from 1990, the earliest that could adequately resolve the seiche activity in the Harbour, was analyzed.

Fig 4B shows the power spectrum (the distribution of variance per unit frequency versus frequency) of the North Sydney sea level record which runs from January 27 to June 27, 1990. The spectrum shows the expected tidal peaks around ~1 cpd (diurnal) and

~2 cpd (semi-diurnal) as well as a broad peak, centred at ~12 cpd, the expected periods of the two fundamental modes of the Harbour estimated by Honda and Dawson (1911). Integrating the spectrum across this frequency band (inset, Fig 4B) yields an average harmonic amplitude of 0.066 m. This indicates that seiches can make significant contributions to sea level variability in the Harbour, compared to the leading diurnal component (K1, 0.93 cpd) with an amplitude of 0.082 m and the largest semi-diurnal component (M2, 1.93 cpd) at 0.38 m. There are 2 peaks evident in the 8-14 cpd band: the first at (~11.4 cpd (period 126 minutes, inset Fig 4B) corresponds to the fundamental seiche periods of Honda and Dawson (1911) and Easton (1972); the width of this peak (~1 cpd) is the same as estimated by Easton (1972) as the variation of the seiche period due to high and low water levels due to tidal variations. The second peak, at 9.47 cpd (152 minutes), corresponds to the edge waves suggested by Easton (1972) as the external driver of the seiches in the Harbour. During this 6-month period, a peak seiche amplitude of ~0.45 m occurred in late February (Fig 4C).

The Easton (1972) model indicates that the seiche amplitude averaged over the South Arm should be 1.24 times larger than at the North Sydney tide gauge. For the following estimates though, it is assumed that the elevations observed at North Sydney apply to the South Arm. The average current across the mouth of the South Arm required to give the observed sea level elevations (from minimum to maximum elevation) associated with the tides and the seiche band can be estimated as $4*As*\zeta/(Ax*\tau)$, where As is the surface area (=11.1 km^2) of the South Arm, ζ is the sea level amplitude, Ax is the cross-sectional area (27265 m^2) of the mouth of the Arm, and τ is the period of the component in question. For a seiche with a sea level amplitude of 0.066 m, the current would be 0.015 m s^{-1}. Easton (1972) indicates that seiche amplitudes of 0.15 m are common; this would correspond to currents of 0.035 m s^{-1}. The peak amplitude of 0.6 m he reported corresponds to a 0.15 m s^{-1} flow. Ninety-five percent of the 1989-1999 15-minute observations in the high-pass series were less than 0.141 m; about 1% of the observations exceeded 0.2 m.

Forces driving the seiches

The response of Sydney Harbour can be examined in light of the classic, externally-forced single-degree-of-freedom model of a rectangular harbour developed by Miles and Munk (1961, Fig 5A).

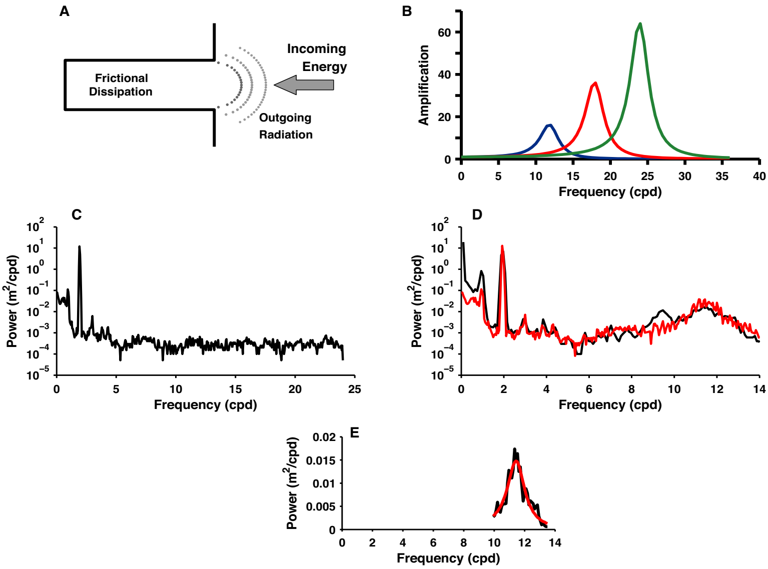

Fig 5 **A) Schematic of Miles-Munk (1961) harbour model. The large grey arrow depicts the incoming energy from the adjacent ocean. Frictional dissipation within the harbour is due to current flow over the harbour bottom. The dots outside the mouth of the harbour illustrate energy radiated back to the ocean. B) Amplification factor for resonant periods of 12 (blue) 18 (red) and 24 (green) cpd with Q values of 4, 6, and 8 respectively. C) St. Ann's Bank winter-spring sea level spectrum serves as the input of the model. D) Comparison of North Sydney sea level spectrum (black, see Fig 4A) with model spectrum (red, =St. Ann's Bank spectrum * model response function). E) Smoothed, least-squares best fit of model response function to North Sydney sea level spectrum (see Fig 4B) in frequency band of 10-13.5 cpd.**

While the passage of an atmospheric pressure front or wind shifts can generate seiches directly within the harbour, Miles and Munk (1961) maintained that excitation through the harbour mouth by the broad spectrum of external wave-like motions is the main cause. The sea level response of the harbour depends its natural frequency, which in turn rests on the harbour's geometry, the frequency of the incoming energy, dissipation within the harbour and the radiation of energy from the harbour mouth back out to sea. They parameterize the overall dampening of the seiche as inversely dependent on the parameter Q which is composed of two parts, frictional dissipation in the harbour and radiation of energy back into the open ocean. A harbour with a low (high) value of Q both adjusts to the incoming external wave motions and dampens the harbour response quickly (slowly).

Fig 5B illustrates the impact of Q on harbour response with lower power amplification with Q = 4 (more dampening), resonance period energy magnified by a factor of 16, and greater amplification with Q = 8 (less dampening), magnification by a factor of 64. Miles and Munk (1961) argue that the main dampening mechanism generally is the radiative loss of energy through the harbour mouth rather than through bottom friction within the harbour.

By combining an offshore sea level spectrum with the Miles-Munk model, the harbour response can be estimated and compared to the observed response within the harbour. The offshore spectrum comes from a bottom pressure gauge on a mooring located on St. Ann's Bank (46.18 °N, 60.22 °W) about 83 km east of Sydney Harbour, water depth 108 m (Fig 5C). The data were collected during the winter and spring of 2015 and therefore are not contemporaneous with the North Sydney sea level observations. Nonetheless, they should provide some insight on how the offshore energy is amplified in the harbour. Between 5 and 24 cpd, the spectrum is quite flat with an integrated amplitude equivalent to 0.107 m sea level displacement. This spectrum serves as the input to the Miles-Munk model and the resulting response for the harbour (red line, Fig 5D) is compared to the observed response (black line, Fig 5D). Focussing on frequencies near the expected fundamental resonance (10-13 cpd), the agreement of the modelled (St. Ann's spectrum* model amplification) and the observed North Sydney sea level spectra is excellent. On the other hand, at frequencies of ~9 cpd, the observed spectrum is consistently more energetic than the modelled one. However, this is precisely (at 9.5 cpd) where Easton (1972) expected to find coastally-trapped waves whose amplitude are likely attenuated at the offshore St. Ann's Bank mooring site. Munk *et al.* (1956) give the offshore scale, L, of the edge waves as $U^2/g*\sin(\beta)$, where U is the speed of the travelling disturbance and β is the bottom slope. Using the values in Easton (1972) gives an offshore scale of ~10 km. It is reasonable then that the energetic edge waves at ~9.5 cpd are attenuated at St. Ann's Bank and therefore not present in the record. The amplification function used in the spectral comparison (Fig 5D) was based on a least-squares fit in the frequency band 10-13.5 cpd (Fig 5E). The fit ($R^2 = 0.89$) gives a Q of 8.3 at a resonant frequency of 11.5 cpd (period of 125 minutes); Easton's (1972) model found a resonant period of 124 minutes.

Currents associated with seiche oscillations

A 100 h segment (Oct 2-6, 1987) of the recorded, along-harbour currents (blue line, Fig 6A; data from Lane (1989, 1991)) from just outside of the mouth of the South Arm shows the dominant flows, the underlying semi-diurnal tidal current (shown in red for clarity) and the high frequency seiche motion with a period of ~2 h (Fig 6B).

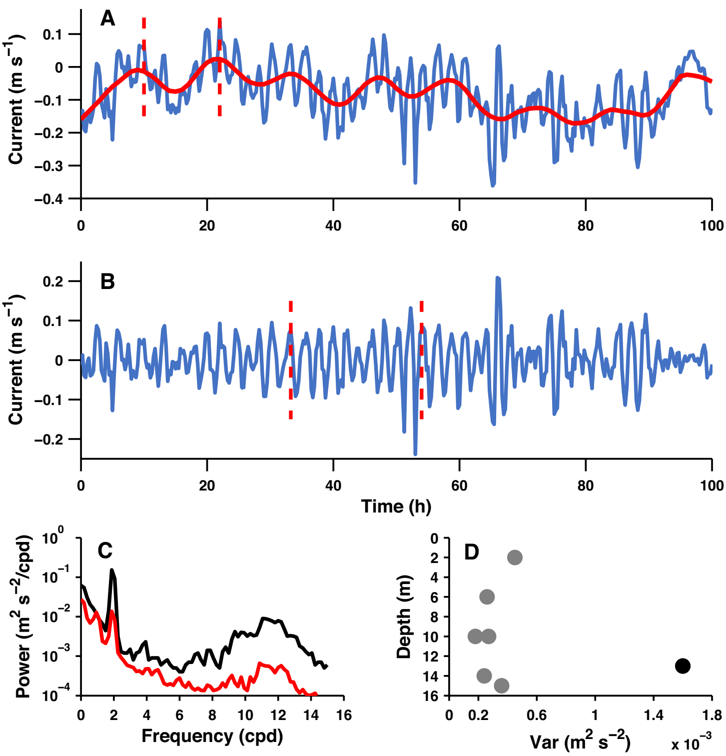

Fig 6 **A) Section (Oct 2-6, 1987, blue line) of the current meter record from just outside the mouth of the South Arm of Sydney Harbour; data shown are positive along 178°, the direction of maximum variance and approximate orientation of the South Arm. The red line is a filtered version to emphasize the tidal flows. Vertical red lines span 12 hours. B) Time series of current meter record shown in Fig 6A after it has been processed using a high pass filter. The vertical red lines correspond to a time span of 20.75 hours. C) Spectra of the current meter time series from outside the mouth of the South Arm resolved along 178° (black line), and from the ASA ADCP series in the South Arm (red line), the average of the 2, 6, 10 and 14 m spectra. D) High frequency variance of current meter data from the moorings in the South Arm (grey points) and just outside the mouth of the South Arm (black point; see Fig 1A, B for locations). Five of the six records from the South Arm are from August, one from Jan-Apr.**

The seiche current has a representative speed of ~0.07 m s^{-1} and a peak flow of 0.24 m s^{-1}, stronger than the tidal current amplitude of ~0.04 m s^{-1}.

The power spectra of series outside and inside the South Arm show the expected strong semi-diurnal peak at ~2 cpd and the broad peak centered about 12 cpd (Fig 6C). The outer spectrum is more energetic than the one from within the Arm. The ratio (outside/ inside) of the variances for the band 10-14 cpd is ~13. The semi-diurnal tidal band corresponds to an amplitude of 0.114 m s^{-1}, the seiche band to 0.049 m s^{-1} for the outer series, whereas, for the South Arm record, the equivalent currents are 0.019 and 0.01 m s^{-1}.

The high frequency variance outside the mouth is about 5.5 times greater than that within the Arm (Fig 6D). However, it should be noted that these records are not contemporaneous.

The current meter data consist of short records and for the greater part are confined to the summer months (5 of 6 are from August, 1 from January-April) when seiche activity might be reduced. We can use the sea level data subjected to a high pass filter and continuity (flow into (out of) the harbour gives rise to an increase (decrease) of sea level) to obtain some idea of currents in the South Arm. Seiche current estimates were made using the high pass filtered 1989-1999, 15-minute sea level observations from the North Sydney gauge; their distribution suggests that most current speeds are low, 79% are less than 0.02 m s^{-1}. These estimates are in excellent agreement (root mean square difference = 0.34%) with the combined current meter data observations in Table 1.

Table 1 Comparison of the percentage distributions of seiche current speeds estimated from sea level observations (SL, 336,577 points) and in situ current meter data (CM, 23,208 points). Maximum in situ current speed was 0.24 m s-1.

m s^{-1}	0-0.02	0.02-0.04	0.04-0.06	0.06-0.08	0.08-0.10
SL	78.8	17.9	2.6	0.41	0.092
CM	78.0	18.4	2.4	0.074	0.211

Table 1 cont'd

m s^{-1}	0.10-0.12	0.12-0.14	0.14-0.16	0.16-0.18	0.18-0.20	>0.20
SL	0.028	0.010	0.0032	0.0021	0.0015	0.0006
CM	0.069	0.047	0.0043	0.0043	0.0043	0.013

Tidal flows

The ASA (1994) study tabulated the results of analyses of the tidal currents in Sydney Harbour, including ADCP records from off Muggah Creek sampling from 2-14 m at 1 m resolution (Fig 1A for location). Using those tables, we find that the amplitude along the major axis of the tidal ellipse of the principal semi-diurnal constituent, M2, was ~23 times greater (median value of the 13 depths) than along the minor axis; the major axis was oriented along the harbour at all depths (range of direction was from 155° to 162° True). In Table 2, the currents at the mouth of the South Arm derived from harmonic analyses of sea level amplitudes from the North Sydney gauge are compared to results presented in the ASA (1994) report for the single point current meter and the ADCP. The sea level-derived currents for the 5 principal tidal components are given by the formula $U = 2\pi * As * \zeta / (Ax * \tau)$. The current phase should lead the sea level phase by 90°. The tidal flows are quite small with only M2 currents exceeding 0.01 m s^{-1}; moreover, 8 of 9 comparisons are within 0.005 m s^{-1} of each other, the exception is the M2 current for 1993. The comparison illustrates the utility of simple principles, in this case continuity, given the availability of long-term observations of sea level to estimate current velocities.

Table 2 Comparison of the tidal flows along axis of Sydney Harbour derived from sea level elevations (U) and from ASA moored current meters, at 10 m in 1992 and 1993.

	M2	S2	N2	K1	O1
Period (h)	12.42	12	12.66	23.93	25.82
Z (m)	0.368	0.109	0.076	0.077	0.082
U (m s-1)	0.021	0.006	0.004	0.002	0.002
ASA 1992 (m s-1)	0.017	0.006	-	0.007	0.003
ASA 1993 (m s-1)	0.008	0.005	0.004	0.002	0.003

To complete the picture, the depth profiles of the M2 (principal semi-diurnal) and K1 (principal diurnal) major axes current amplitudes and phases are shown in Fig 7. While there is a systematic variation of amplitudes and phases with depth, with such low velocities a detailed investigation is not pursued here. However, given the relatively short (~1 month) duration of the record during the summer when stratification is strong, an M2 internal tide, with opposing velocities in the upper and lower layers superimposed

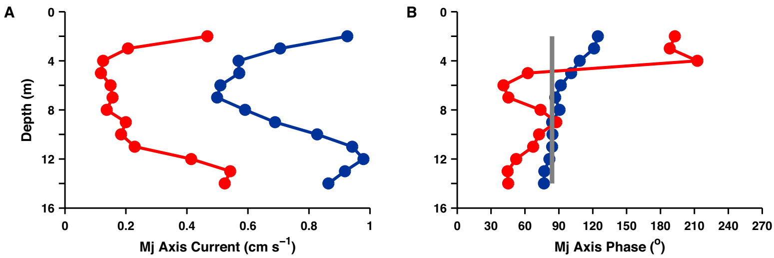

Fig 7 A) Depth profile of M2 (blue) and K1 (red) major axis currents in the South Arm of Sydney Harbour. B) Depth profile of M2 (blue) and K1 (red) major axis phases. Tidal analyses are based on a 1993 ADCP record collected by ASA (1994). Grey line represents the M2 current phase calculated from the M2 tidal constant derived from the North Sydney sea level record.

on the usual tide (i.e. velocity constant with depth), could cause the observed velocity and phase structure. Note the M2 current phase, a measure of the temporal relationship of this component to the lunar forcing, derived from the sea level data agrees with the phases calculated from the in situ ADCP observations (Fig 7B). At the latitude of Sydney Harbour, diurnal internal waves cannot be generated, though other types of waves with vertical structure can exist and lead to variations of velocity and phase with depth. The weak tidal currents suggest they play only a minor role in the dynamics of the South Arm of the Harbour. In fact, using representative velocities for the Harbour to examine the M2 dynamics, the acceleration terms exceed the frictional terms by a factor of 50. By comparison, the peak seiche velocities, while episodic, can exceed 0.1 m s^{-1}, an order of magnitude greater than that of the tidal components.

Mean flows

The South Arm features surface outflow and mid-depth and deep inflows (Fig 1B) and given the freshwater inflow from Sydney River, this is consistent with estuarine circulation (e.g., Geyer and MacCready, 2014). The mean currents along and across the Arm from the DFO deployment suggest the same picture: near-surface currents are northward, towards the mouth, deeper flows are towards the head (Fig 8A,B). It is apparent that these profiles have more inflow than outflow. To achieve a local balance requires a surface current of ~2.5 cm s^{-1} at the western mooring which seems reasonable; on the other hand, a surface flow of 7.9 cm s^{-1} would be

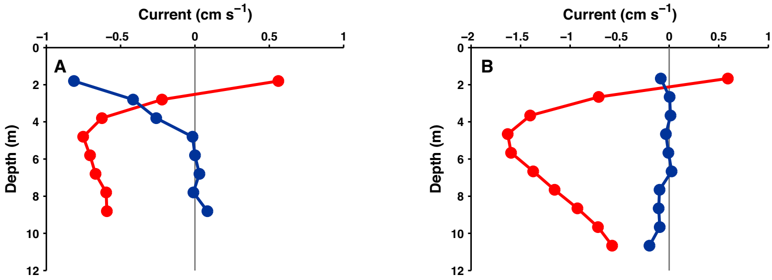

Fig 8 **A) Profile of mean along-harbour (positive towards 10° True, red) and across-harbour (positive towards 100° True, blue) currents from the DFO deployment off the western side of the South Arm May 2001-Oct 2002. B) Profile of mean along-harbour (positive towards 2° True, red) and across-harbour (positive towards 92° True, blue) currents off Muggah Creek May 2001-Oct 2002.**

necessary for the mooring off Muggah Creek. This flow is much stronger than any of the observed mean currents and seems more unlikely. Combining the 1 m vertical resolution of the moorings and representative widths across the Arm for the 2 moorings at each depth, there is a net transport towards the head of ~63 $m^3 s^{-1}$. To balance this flow requires an outflow of 0.047 m s^{-1} in the surface layer (~1.2 m not sampled by the instruments) across the breath of the Arm. Though high relative to all the measurements, a current of is magnitude cannot be ruled out. On the other hand, these two moorings, despite their proximity, may not have sampled the spatial structure of currents adequately.

Hydrographic sections along the axis of the South Arm in May 2001 and October 1999 reinforce the estuarine nature of the circulation. The temperature and salinity sections from May 2001, a period when stratification is developing, are characterized by 3 layers (Fig 9A,B): the first, from the surface to ~2 m, is highly variable along the Arm. Within 2 km of Sydney River, the salinity increases rapidly from about 4 to >27, suggesting strong entrainment of deeper, saltier waters into the river discharge. Areas of relatively warm, freshwater are interrupted by stretches of cooler, saltier water. The transit time in the surface layer from the head to the mouth ~10 d (13 km at a representative velocity of 0.01 m s^{-1}) coupled with varying freshwater inflow could have contributed to the variation of salinity. From 2 to 9 m, the structure is more uniform with temperatures of 2-3 °C and salinities of 27-28. Below 9 m, temperatures are 0-1 °C, salinities generally >29. The October sections feature

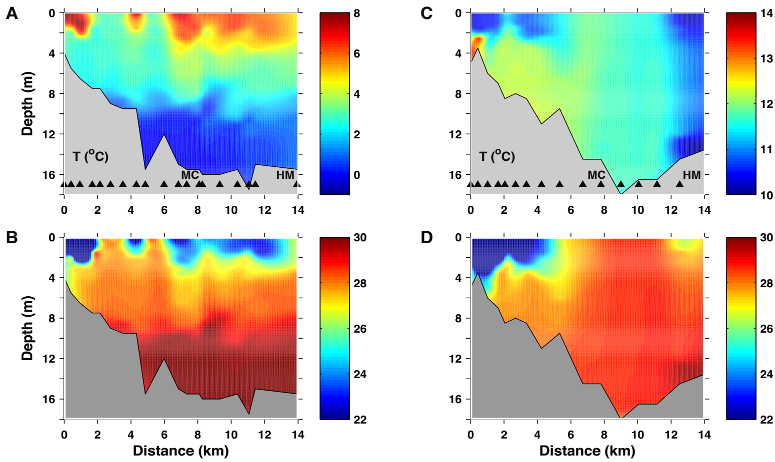

Fig 9 A) Temperature section along the axis of the South Arm, May 2001, from just seaward of Sydney River (distance 0 km) to outside the mouth. Temperature/salinity stations are indicated by an arrowhead at 17 m. The locations of Muggah Creek (MC) and the Arm mouth (HM) are shown. B) Salinity section. C) Temperature and D. salinity sections, Oct 1999.

weaker vertical gradients than in May, with the exception of the pronounced wedge defined by salinity beginning at Sydney River and extending nearly 5 km down the Arm (Fig 9C,D). The surface salinity was ~4, the 4 m salinity was 25.6 at the first station in this section; 5 km along the Arm, surface salinity was 26.4. The wedge was a region of strong entrainment from the deeper waters into the surface layer. Vertical gradients of temperature and salinity in the outer half of the Arm are weak likely due to a breakdown of stratification at this time of the year.

DISCUSSION

More than a century ago, Dawson began the collection of sea level observations for Sydney Harbour as part of broader program focused on safe navigation in ports and in open water shipping lanes on the Canadian Atlantic coast. In 1970, the Canadian Hydrographic Service continued this work through the establishment of a tide gauge at North Sydney, maintained to this day and the basis for much of the analysis presented here.

There is a distinct annual cycle in sea level variance – high during the winter, low from late spring to early fall – that is the result of increased energy across all frequency bands with the exception of the tides. The largest increases were in the storm band (0.2-1 cpd).

Dawson observed a high frequency seiche in the South Arm of Sydney Harbour with a dominant period of ~2 h and elevations comparable to those of the tidal constituents. In collaboration with Honda, the seiche was identified as the fundamental harbour mode. The spectrum of the record presented here featured a seiche with a period of 125 minutes, essentially the same as that derived by Honda and Dawson (1911) and Easton (1972). In addition, another spectral peak was identified at 152 minutes, the same period calculated by Easton (1972) for external edge waves hypothesized to drive seiches in the Harbour.

Given the importance of seiches in the Harbour, an analysis of frequency of occurrence of sea level elevations was conducted. The results (based on the 1989-1990, 15-minute, ~336,000 observations, filtered to retain frequencies > 6 cpd) indicate that 50% exceeded 0.05 m, 5% were greater than 0.136 m, 0.01% exceeded the M2 tidal amplitude of 0.38 m. The maximum observed amplitude was 0.74 m. The maximum seiche current was 0.24 m s^{-1} from the limited in situ current meter data. Easton's (1972) model suggests that the seiche amplitudes in the South Arm might be as much as 35% higher than those recorded by the North Sydney gauge. However, a comparison of a limited series of surface elevations in the South Arm with contemporaneous North Sydney data suggests the amplification indicated by Easton (1972) was overestimated (Fig A2).

The analysis of current meter data (Fig 7C) indicates substantially more energy in the seiche band outside the South Arm with the ratio (outside/inside) of variances about 13. Easton (1972) gives the structure of the current transports along the Harbour for the first modes. To convert transport to current requires knowing the cross-sectional areas used in the model, however, they are not given. Using the chart for Sydney Harbour to estimate the cross-sections yields a ratio of current variances of 4-12, the major uncertainty arising from the estimate of the cross-section outside the Arm at the current meter site. Given that the current series were collected at different times, the comparison lends some support to the model.

Application of the Miles-Munk (1961) spectral model suggested that offshore forcing does indeed drive a response in the Harbour with the dissipative parameter Q = 8.3. This compares with values of 2.3 (more dissipation/radiation) for Oceanside, California and 11.2 (less dissipation/radiation) for Acapulco, Mexico which were estimated from the data in Miles and Munk (1961). From Okihiro *et al.* (1993), a Q of 8.8 was calculated for the fundamental mode of Barbers Point Harbor, Hawaii, which is about one tenth the size of Sydney Harbour. Okihiro *et al.* (1993) identified two other higher frequency but lower energy seiches in the sea level spectra from the Harbor. One appears to be the first harmonic of the fundamental mode; the second appears to be a separate harbour mode. Garrett (1972) calculated a Q of 5.3 (±1.5) for the Bay of Fundy. He found that the radiative component (Q_R = 6.8) dominated the dissipative component (Q_D = 18.2), however, he argued that the estimate of Q_D "seems rather high". In the end he states, "It seems unlikely that Q_D for the whole system could be more than about 10."

Both Honda and Dawson (1911) and Easton (1972) mentioned only observing the fundamental mode for Sydney Harbour. The CHS and the Marine Environmental Data Service (Fisheries and Oceans Canada, Ottawa) provided sea level records from North Sydney sampled at 1-minute intervals which enabled the higher modes to be resolved. The spectrum of a record from Jan 4-May 26, 2015 shows the fundamental (zeroth, ~11.6 cpd) mode as the most energetic (Fig 10). Mode 1 (31.6 cpd from Easton's (1972) model) does not

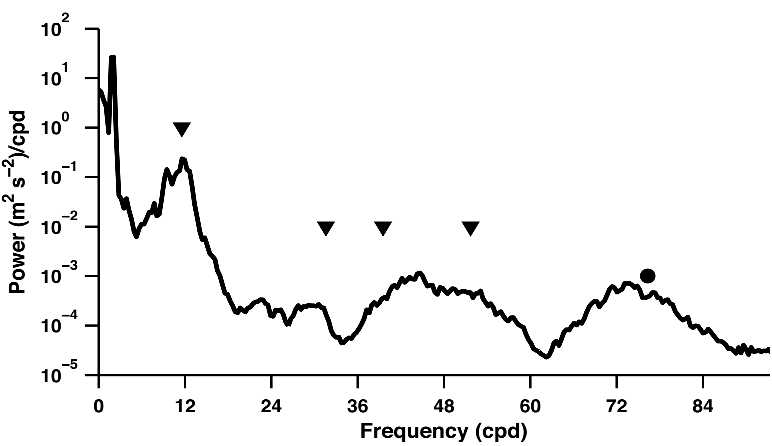

Fig 10 Spectrum of North Sydney sea level. Record was from Jan 4-May 26, 2015, sampled at 1-minute intervals. The downward arrows are the seiche frequencies (modes 0-3, where 0 is the fundamental mode) predicted by the model of Easton (1972). The dot is mode 4 projected from modes 1-3.

seem to be present, consistent with Easton's result that indicates a nodal point for this mode near the North Sydney tide gauge. Modes 2 (39.5 cpd) and 3 (51.7 cpd) correspond to a broad peak from 33 cpd to 62 cpd. The projected mode 4 at 76.3 cpd corresponds to a second broad peak from 62 cpd-88 cpd. In this spectrum, the fundamental mode is equivalent to an amplitude of 0.064 m (integration from 11-14 cpd), the broad peak for modes 2 and 3 to 0.01 m, and the projected mode 4 to 0.0075 m. Clearly, the fundamental mode dominates; the higher order modes reported here have variances 2.3% (modes 2, 3) and 1.4% (mode 4) of the fundamental.

Tidal currents in the South Arm are weak with the leading M2 constituent having an along-harbour velocity of 0.01 m s^{-1}. The appearance of tidal harmonics (e.g., Fig 3A), usually confined to areas, such as the Bay of Fundy, where tidal velocities are strong and frictional dissipation is large, was surprising. The mean flows also were weak with speeds of about 0.01 m s^{-1}.

Given the relatively strong freshwater inflow from Sydney River, it is reasonable to expect estuarine circulation dominating the mean flows in the Arm. The limited hydrographic data, showing strong gradients in the first 2 to 5 km from Sydney River, support strong entrainment of deeper saltier waters into the surface layer.

Despite the weak mean circulation in the South Arm, the distribution of polycyclic aromatic hydrocarbons (PAH) in the sediments suggests the average currents may play an important role. Vandermeulen (1986) indicated that the major source of PAH is from Muggah Creek. The map of PAH concentrations in the Harbour shows by far the largest concentrations at and just outside of Muggah Creek (Fig 11). The inset depicts the concentrations on the eastern side of the South Arm, with the tendency of higher values towards Sydney River rather than towards the mouth. Petrie *et al.* (2001) used the Lane January-April 1988 current meter data to drive a bottom boundary layer model to examine the re-suspension, transport and re-settling of sediments (bblt; Hannah *et al.*, 1995). In the model, bottom sediments were characterized by a distribution of critical stress values – at low stresses only the finer fraction would resuspend; as currents and consequently stresses increased, a larger fraction of the sediments would be lifted into suspension. Once suspended, the sediments are subject to the vertical structure of the currents and vertical mixing. For the January-April period, there were 17 events when at least 40% of the sediment was re-suspended. As the sediments sank and re-settled, their overall tendency was to move upstream towards Sydney River and re-settle on the bottom. These results are consistent with the measured bottom concentrations of PAH shown (Fig 11). More recently, analysis of cores for metals and organic contaminants in Sydney Harbour by Smith *et al.* (2009; see Table 3) show elevated levels of lead and PAH inventories towards the head of the Arm relative to those towards the mouth in agreement with the observations presented by Vandermeulen (1986).

While his main objectives were to acquire sea level data for ports and shipping lanes for Atlantic Canadian waters and to establish a long-term tide gauge network, nonetheless, W. Bell Dawson spent time exploring the dynamics of the time series he acquired. Consequently, he identified the seiches in Sydney Harbour and

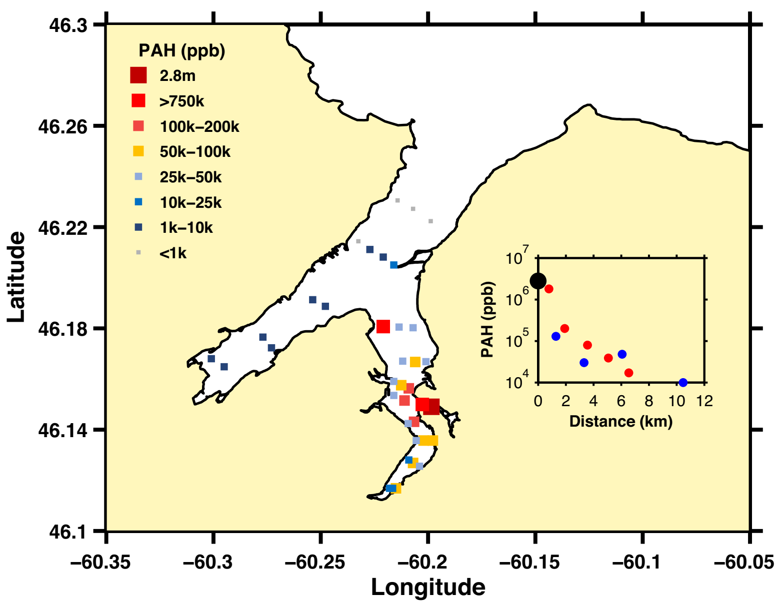

Fig 11 **Map of PAH stations and concentration in parts per billion. Stations are colour- and size-coded according to concentration. The inset shows the PAH concentrations of stations on the eastern side of the South Arm. Red dots are for sites located in the South Arm on the Sydney River side of Muggah Creek, blue for sites towards the mouth of the Arm. Note the high concentration of PAH on the western side of the South Arm near the mouth. This was a dump site for material dredged in the South Arm. Data are from Vandermeulen (1986).**

Table 3 Lead (Pb) and PAHs inventories of cores from the eastern side of the South Arm. Data from Smith et al. (2009), their Table 1. Negative (positive) distances are towards Sydney River (mouth of South Arm). Distances are from the mouth of Muggah Creek. Station 4b of Smith *et al.* (2009), just outside of Muggah Creek, is the reference station. Npts is number of cores.

Distance (km)	-3 to -2	-2 to -1	-1to 0	Sta. 4b at 0	0 to 1	1 to 2	2 to 3
Pb (µg cm-2)	1918	4195	3758	4507	2435	2621	2026
Npts	3	1	5	1	3	3	2
PAHs (µg cm-2)	881	2268	6211	9905	2544	2023	
Npts	1	2	1	1	2	1	0

recognized their importance to navigation and to conducting port activities safely. His foresight in developing the sea level network and CHS's ongoing maintenance of a gauge at North Sydney enabled the analyses presented here, an extension of research that began more than a century ago.

CONCLUSIONS

Seiches in Sydney Harbour, given their episodic nature and high frequency, have elevations that can exceed the amplitude of the major tidal constituent M2 by a factor of 2; seiche currents in the Arm were ~10 times greater than tidal or mean flows. Consequently, their impact on harbour shipping and safety could be significant. The strong flows due to seiches have the potential to resuspend sediments and affect their distribution on the harbour bottom. Though weak, the persistence of the mean circulation can act to retain contaminants associated with sediments in the South Arm.

The circulation derived from moored instruments and the temperature and salinity sections suggest the development of basic circulation models based on mass and salt conservation, entrainment and two-way vertical exchange. Such models, e.g. for Halifax Harbour, have been successfully applied to hindcast nutrient, dissolved metals, suspended solids and bacterial transport and distribution within the harbour and to forecast changes due to modifications such as sewage treatment (Petrie and Yeats 1990). A proxy for freshwater inflow would be required, likely based on rainfall (or nearby gauged rivers) and drainage basin area since Sydney River has never been gauged.

Simultaneous measurement of sea level at North Sydney and in the South Arm with a sampling rate of at least 15 minutes could verify the Easton (1972) model more definitively than has been possible with the existing observations.

Acknowledgements I thank David Greenberg and Adam Drozdowski for their reviews which helped to clarify the text. Adam Drozdowski raised a number of issues that led to further analyses particularly with respect to potential drivers of the seiches, structure of Easton's (1972) modes and the net transport in the South Arm. My thanks to Phillip MacAulay (CHS) for suggesting the use of the 1-minute sea level data and Jenny Chiu (MEDS) for compiling the times series for 2015-2017. The analysis of these data showed the higher modes in the Harbour that it was not possible to investigate with the series sampled at 15-minute intervals. There were also several useful discussions with Phillip MacAulay on various aspects of seiche activity in coastal embayments. My thanks to the 2 external reviewers for their careful reading of the manuscript and positive suggestions to improve clarity and add some additional material that could be of general interest.

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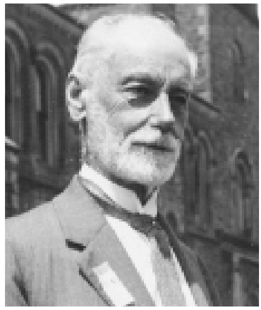

Fig A1 William Bell Dawson, engineer and superintendent of the Tidal Survey, Canadian Department of Marine and Fisheries from 1893-1924.

APPENDIX

Dr. W. Bell Dawson, born in Pictou NS in 1854, was appointed as Engineer-in-Charge of the Tidal Survey of Canada in 1893. He remained with the Survey until 1924. His appointment marked the beginning of a systematic survey of tides and currents in Canadian waters. His comprehensive program of sea level and current observations in Atlantic Canadian marine waters would lead to an improved understanding of the tides and other oceanographic phenomena in this region. The primary focus was on ports and shipping lanes.

Dr. Dawson placed considerable importance on the establishment of benchmarks and datums; these sea level reference points are particularly relevant now with the ongoing interest in rising sea levels. His publication "Tide Levels and Datum Planes in Eastern Canada, 1917" is evidence of his commitment. Dr. Dawson also carried out short period tidal observations at many secondary ports in order to establish their relationship to nearby, permanent tidal stations and enable long-term water level predictions.

Current surveys were also carried out by Dr. Dawson most notably in the Strait of Belle Isle, Cabot Strait, and at the entrances of the Bay of Fundy and the St. Lawrence Estuary. In 1894 his first current surveys were carried out in the Strait of Belle Isle and in Cabot Strait. The main objective of these programs was to quantify the currents along the routes of steamship and sailing vessels on the Atlantic coast. Consequently, the emphasis was placed on near surface (keel-depth) flows which could affect vessel movement. The report of the Belle Isle Strait survey, in particular, provides insight into the scientific mind and thoroughness that Dr. Dawson brought to his work. Dr. Dawson died in Montréal in 1944.

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Models of Honda and Dawson (1911), Easton (1972)

The harbour model of Honda and Dawson (1972) was a rectangle of constant depth, length L. Although this geometry allows for additional modes, Honda and Dawson only discuss the fundamental one. Using their harbour parameters, the next 3 modes would have frequencies of 33, 55 and 76 cpd (Northwest Arm) or 36, 60 and 84 cpd (South Arm). As noted, Honda and Dawson (1911) considered Sydney Harbour to consist of two, non-interacting parts, one from the mouth to the head of the Northwest arm, the second from the mouth to the head of the South Arm.

The one dimensional numerical model of Easton (1972) included the variations of depth and cross-section; the two arms were connected and could interact dynamically. The model dynamics were based on a balance of acceleration and along-harbour sea level gradient, and continuity. Easton (1972) shows the amplitude structure of elevation and transport of the first 4 modes. The first mode is the classic, fundamental one modified by the variations of depth and cross-section. The amplitude structure in the Northwest and South Arms are almost identical. The second mode reported appears to be associated with the South and Northwest arms only, i.e., it has a node at the junction of the south and northwest arms, whose amplitudes are 180° out of phase, and nearly zero amplitude in the outer Harbour. The third and fourth modes resemble the classic first and second harmonics again modified by depth and cross-section variations.

Determination of contribution of annual cycle to monthly mean sea level variance

Step 1 – Calculate variance by month from 15-minute datasets. Results will include contributions from periods of 30 minutes and longer (Fig 2A). Monthly variance = base value common to all months + variation above base value.

Step 2 – Determine the monthly mean sea levels to assess the magnitude of the annual cycle (Fig 2B).

Step 3 – Remove the long-term trend from the monthly sea levels to obtain the monthly residuals (Fig 2C). If the annual cycle of sea level were a pure harmonic and the only contributor, then the residuals would be 0.

Step 4 – Group the values by month from the times series shown in Fig 2C (Fig 2D).

Step 5 – Compare in Fig 2E the variation calculated from Step 1 (Fig 2A) to variance in the annual cycle (Fig 2D).

Comparison of sea level spectra from Westmount ADCP and North Sydney CHS Tide Gauge

The Westmount ADCP was equipped to detect the surface elevation relative to the instrument's position on the bottom. Sampling hourly, the record can resolve frequencies up to 12 cpd (and then only marginally) which corresponds to the fundamental seiche mode of the Harbour. The signal can be noisy because of surface waves interfering with the acoustic backscatter. Nonetheless, between 30 Oct 2000 and 24 Apr 2001, the record of potentially 4220 points sampled hourly had only 13 missing values (3 1-hour and 5 2-hour gaps), by far the best segment of the time series. These missing values were filled using linear interpolation. During the same period, the North Sydney tide gauge (15-minute sampling) had a data gap from 13 Jan-30 Jan 2001. As a consequence of this large gap, the North Sydney record was analyzed in two segments and the results combined. Comparison of the power spectra of these data will suggest how well the Easton (1972) model captured the amplitude structure of the fundamental seiche mode in the Harbour. The model indicates that the seiche amplitude at Westmount will be about 26% larger than that at North Sydney. This is not borne out by the intercomparison (Fig A2), where the spectra suggest that the variances from 9 to 12 cpd are comparable, perhaps even larger at North Sydney. As indicated, the 1-hour ADCP sampling is not ideal to establish the relationship between the two sites.

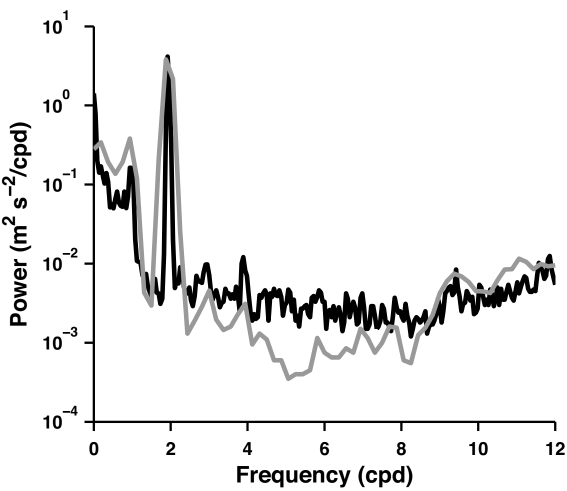

Fig A2 Spectra of the Westmount ADCP surface elevation time series (30 Oct 2000-24 Apr 2001; black line) and North Sydney sea level composite (30 Oct 2000-13 Jan 2001; 30 Jan 2001-24 Apr 2001; grey line).

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TWENTY YEARS OF ECOLOGICAL RESEARCH IN NOVA SCOTIA WILDERNESS AREAS AND NATURE RESERVES: A REVIEW OF STUDIES, 2002 TO 2022

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ABSTRACT

The following paper is a review of the research undertaken over the last twenty years in Wilderness Areas and Nature Reserves in Nova Scotia. A brief summary is presented of the main findings of each research project conducted by the author or contributed to by the author in a significant way. Inventories have included eleven bioblitzes and over four thousand plots from systematic transects. These have revealed significant new records for species including those of conservation concern. Results suggest there are many species than have not been identified in protected areas. Geographical Information System (GIS) Ecological Land Classification was completed for Nova Scotia and this led to ecosystem gap analysis to determine ecosystems that are not well represented in the current protected areas system. Long-term monitoring, using biodiversity transects and lichens, indicates that air quality is good throughout the protected areas system. Forests are returning to a more climax condition and with the exception of a few instances, non-native plants are generally not problematic. Carbon modeling of protected areas suggests that they will be a carbon sink for the next one hundred years and would be a carbon source if managed for forestry. Protected areas are well suited to provide ideal optimal settings in which climate change adaptation and mitigation can take place. Planning for climate change within protected areas can be facilitated by a Climate Change Adaptation Framework.

Research on species of special concern in protected areas has included turtles, Mainland Moose, Canada Lynx, America Marten, Lichens, Atlantic Coastal Plain Flora, forest plants and Piping Plover. Research on rare, sensitive, vulnerable ecosystems has involved predictive modeling and identification and characterization of heathlands, forest wetlands and Jack pine woodlands. Old Growth Forest research has included predictive modeling, biological inventories, dendrochronology studies and scoring using indicators. Human activities adjacent to protected areas can cause deleterious edge effects. An ongoing study in the Cloud Lake Wilderness Area is measuring the effect of adjacent forestry on birds and plants within

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the Wilderness Area. Several studies on connectivity have looked at the increase in connectivity caused by the establishment of protected areas in Nova Scotia. Other efforts on connectivity have identified key nodes of connectivity within the province which require protection. Human use of protected areas can lead to damage of ecosystems and so investigations on human use of protected areas has been focussed on motorized vehicles and to a lesser extent on human foot traffic. Although there have been many ecological studies in protected areas over the last twenty years, it is evident that there still is a great deal that is unknown about the biodiversity of protected areas.

INTRODUCTION

Understanding what needs protection and how it can be accomplished in order to conserve biodiversity is a key element in conservation planning. Research is vital in order to ensure that ecological integrity is maintained in the management of protected areas. Potential human-caused stresses to protected areas need to be identified and how these stresses may affect ecosystems needs to be determined. Protected areas are also ideal sites for research because they can provide benchmarks against which human altered landscapes can be compared. Protected areas represent more natural functioning systems and thus provide the best opportunity for studying changes occurring in natural areas.

In the early 2000s, Protected Areas and Ecosystems Branch (PAE) of Nova Scotia Environment, began a concerted effort to increase research in Wilderness Areas and Nature Reserves (Cameron 2010a). At the time, very little was known about the biodiversity within protected areas, how well protected areas were conserving species and ecosystems, or how they contributed to conservation in Nova Scotia and Canada. Increased research efforts were implemented by encouraging and developing partnerships with other research organizations and individuals. Partnerships included contributions from PAE in the form of ideas, staff time, finances and in-kind support. In addition to partnerships, PAE began its own in-house research. Systematic biodiversity surveys were conducted in protected areas, as well as projects examining specific questions such as how much edge effect occurs with adjacent human activity.

This paper does not describe all research that has taken place within Wilderness Areas or Nature Reserves by all researchers as much of this is already in published literature, and some is cited in this paper. Rather, the research reviewed here documents studies conducted in Nature Reserves and Wilderness Areas of Nova Scotia that comprise the largest total area of any type of protected area in the province. These are mostly terrestrial environments but do include some aquatic ecosystems, wetlands and marine tidal areas. Other designations of protection such as provincial and national parks are not reviewed.

Each study documented in this paper has its own specific aim or objective. Each helps to contribute to a greater understanding of the ecology, biodiversity and human use and impacts in protected areas. How each study contributes to this greater understanding and knowledge is outlined. This paper is divided into twelve general topic areas which include a number of sometimes unrelated studies. Some studies have overlap between general topic headings and thus some studies will be described more than once.

INVENTORY

Transects

In 2002, Protected Areas and Ecosystems (PAE) began a systematic survey of biodiversity in existing and proposed protected areas (NS Environment 2016). The survey consisted of transects that traversed the variety of ecosystems and included plant community quadrats in each new plant community encountered on the transects. Birds, observed or heard, were recorded as well as any species of other taxa that were of known conservation concern. The methodology enabled calculation of density and population estimates and this was done for species of conservation concern by Cameron (2019). In total, 437 plant abundance and community documentation plots were established, 413 km of transect were traversed, with 4130 presence plots established in 90 existing and proposed Wilderness Areas and Nature Reserves (Cameron 2021).

A number of indices of biodiversity can be calculated using transect data, and these have been summarized by Cameron (2020b). The data and indices have enabled a better assessment of biodiversity captured by protected areas in NS. Cameron (2019) assessed the fine filter – coarse filter approach used by PAE. The fine filter used by PAE consists of capturing habitat, occurrences or potential habitat for rare or at risk species and ecosystems. Coarse filter approach involves capturing the variety of ecosystems with the expectation that the majority of species will be captured (Cameron and Williams 2011). Cameron (2019) found that protected areas aimed at capturing the variety of ecosystems did not tend to capture rarer species that are often of conservation concern. Inclusion of a fine filter approach in conservation planning was needed to capture these rarer species. Cameron (2021) also found that for some species of conservation concern, declines in the broader landscape may not be occurring in protected areas in Nova Scotia. Similar trends are found elsewhere in the world (Geldman *et al.* 2013), suggesting that human impacts on species of conservation concern may be less in protected areas.

Transect data were also used to assess potential impacts of non-native species. Non-native species can become invasive, dominating or changing ecosystems and communities and thus eliminating or degrading habitat for native species (Jeschke *et al.* 2014). Cameron (2021) found nineteen species of non-native plants and no non-native species of birds in protected areas. Most frequently found non-native plants were red raspberry (*Rubus ideaeus* subsp. *strigosa*) and creeping buttercup (*Rannuculus repens*), although mean cover (percent coverage of plot) was low in all sites. Meadow fescue (*Fescue pratensis*) and Japanese knotweed (*Reynoutria japonica*) had the highest mean cover, but each occurred at only one site. Generally, Cameron (2021) found that non-native plants were confined to road sides, ditches and trails and very few species were found in interior habitats. The one exception was floodplains, which Cameron suggested needed a special effort to ensure that ecological integrity was maintained.

Ecosystem richness (number of different ecosystems) has been calculated for protected areas using transect data. In addition, identification of special, rare and unique habitats has been possible using the transect data. Some of these are described by Cameron and MacKinnon (2008), Cameron (2008) and Cameron and Bondrup-Nielsen (2013). These will be further explored later in this paper (see section on Rare, Sensitive, Vulnerable Ecosystems).

Plant and bird species richness has been calculated for protected areas (Cameron 2021), allowing for comparisons between protected areas, ecosystems and Natural Landscapes (ecological land classification system used by NS Environment and Climate Change). Plant and bird data have also been used to assess the effectiveness of protected areas in capturing biodiversity in Nova Scotia. Cameron (2021) used the Species Area Relationship (SAR), following methods of Desmet and Cowling (2004) to calculate the number of plant and bird species expected to occur in each Natural Landscape. Results indicate that there are considerable differences in the expected number of species between Landscapes (Fig 1). Some trends in species richness are apparent. For example, there is high species richness in Landscapes with high productivity or structural complexity, such as LaHave Drumlins, Shubenacadie Rolling Hills and the Cobequid Hills. Equally clear is the low species richness in Landscapes with low productivity, such as the Shelburne Barrens or Canso Coastal Barrens. Less clear are trends of low species richness in Landscapes with high productivity such as Chignecto Slopes or Landscapes with high structural complexity, such as in Cape Breton Highlands region. Some of these less obvious trends could be an artifact of low sample size. Other trends are likely related to the small area of the Landscape such as found in the numerous and small Cape Breton Highland Landscapes. It was also found that Landscapes with high plant species richness did not necessarily have high bird species richness. An assumption of this approach is a log-linear relationship between area and number of species (Fig 2). This assumption has been tested frequently

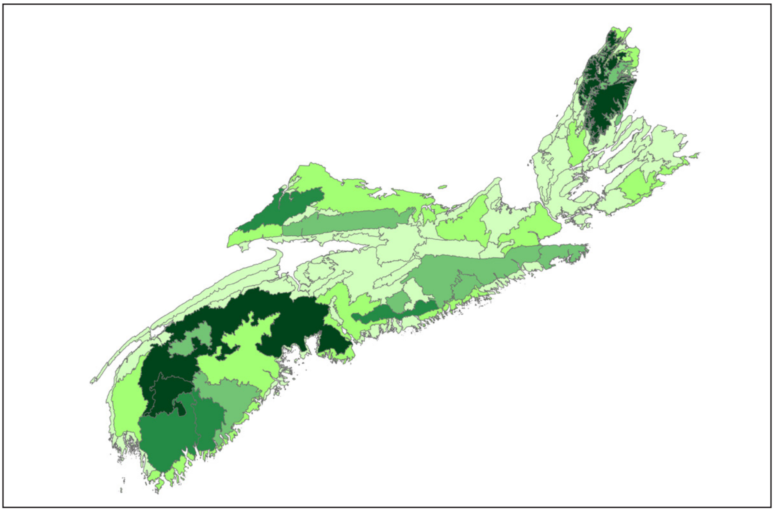

Fig 1 Relative richness of plant species (z score) by Natural Landscape. Lighter green shade indicates greater plant species richness.

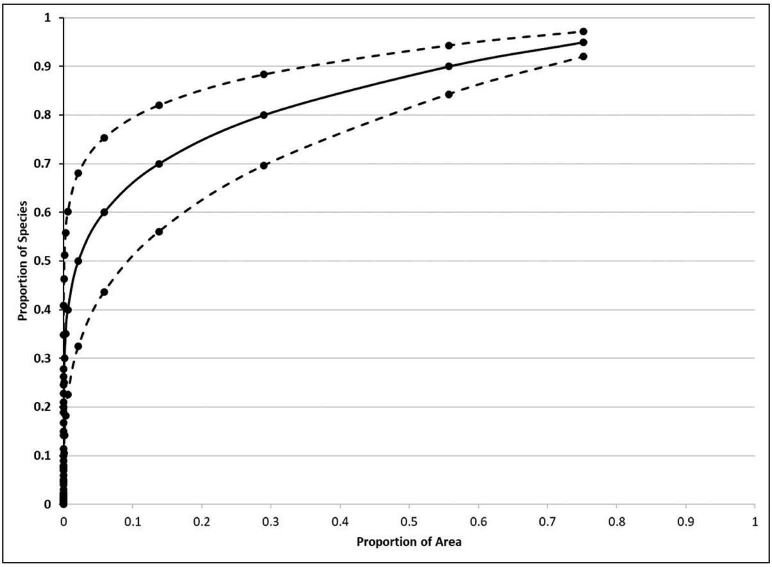

Fig 2 SAR curves using lowest, highest and mean z values for plant species in Natural Landscapes in Nova Scotia.

and has held true for multiple different taxa and multiple different scales (Lomolino 2001, Haila 2002). This assumption, when used in conservation science, has several important implications. The most significant implication is that as protected areas are established, initially the number of species captured increases very rapidly as a function of the size of the area and then levels off quickly. There is a point at which increases in the area under protection results in progressively smaller increases in the number of species captured. Finding this leveling–off point is valuable for determining the most efficient total amount of area of the overall system to protect to capture the most species (Desmet and Cowling 2004).

Herbarium Collections

In 2007, PAE entered an agreement with the E.C. Smith Herbarium, Acadia University, to house voucher samples of plants documented in the transect surveys. This arrangement provided a protected areas reference collection that can be examined by future researchers. Further contributions to this collection were made in partnership with the Harrison Lewis Centre and Acadia University, K.C. Irving Environmental Science Centre. Two students from the

Harrison Lewis Centre and a technician from Acadia University surveyed and collected plant specimens from the Port L'Hebert Nature Reserve in 2016. Collections were further augmented with the collection of marine algae in the adjoining shoreline with guidance from Dr. David Garbary of St. Francis Xavier University. About 250 specimens are now housed in the herbarium.

Bioblitz

Protected Areas has participated in eleven bioblitz events, five of which were led and organized by PAE and in four of which PAE was part of a larger organizing committee. The term "bioblitz" was first used during an event held at the Kenilworth Aquatic Gardens in Washington, DC, in 1996 (Shorthouse 2010). Over time, bioblitzes have become a useful tool for scientists to rapidly assess the biodiversity of protected areas, establish new species records for an area, and at times identify new species.

The first bioblitz involving PAE was in conjunction with the Biology Department of St. Francis Xavier University. This was the first multi-disciplinary bioblitz in Nova Scotia and was held at Canso Coastal Barrens Wilderness Area. Ten scientists and students conducted an inventory of a variety of species groups over a single day (Garbary *et al*. 2006). Since then, multi and single day events have occurred in six Wilderness Areas and one Nature Reserve.

Since bioblitzes have focussed on documenting the species present, the most significant results are in new records of species or new locations for species of conservation concern. In terms of new species records, the most noteworthy find was a previously undescribed species of fungus, *Trifoliellum bioblitzii*, discovered in 2009 during a bioblitz of the Blue Mountain-Birch Cove Lakes Wilderness Area by Strongman and White (2011).

One of the most extensive and comprehensive bioblitzes in Nova Scotia occurred on Scatarie Island Wilderness Area where PAE invited 15 scientists and students to conduct inventories on the island in August, 2005. Surveys took place over three days and included vascular plants, birds, beetles, fish and aquatic invertebrates. Organizations taking part included Cape Breton University, St Frances Xavier University, NS Environment and NS Department of Natural Resources (Williams and Cameron 2010). Many new records of species were found. For example, ninety-four species of Coleoptera were newly recorded for Scatarie Island. Seventeen of these species were recorded for the first time for Cape Breton Island and five were new records for Nova Scotia (Majka *et al*. 2010). The lichen list included five new records for Cape Breton and three new records for Nova Scotia (Cameron *et al*. 2010a). Vascular plant surveys included 15 species new for the Island (Ferrier *et al*. 2010) and 22 species of marine invertebrates not previously recorded for the island (White *et al*. 2010). Similar new records were found in other bioblitzes such as for Lake Rossignol Wilderness Area where 285 of the 294 species documented were new records for the protected area (Anderson *et al*. 2012). The discovery of 12 new species of conservation concern in the Lake Rossignol Wilderness Area was also of note. Findings from nine other bioblitzes in Ship Harbour Long Lake, Tangier Grand Lake, Blue Mountain Birch Cove Lakes, Pollet's Cove Aspy Fault Wilderness Areas and Abraham's Lake Nature Reserve were not published but lists of occurrences are deposited in the PAE database and voucher specimens in various museums. The large numbers of new species-occurrence records for protected areas reflect the limited state of knowledge of biodiversity in protected areas and within the province as a whole.

Transect surveys provide a systematic survey of elements of biodiversity which enable the calculation of densities and populations for temporal and spatial comparisons. This enables managers to assess whether the biodiversity was more or less than expected, determine trends, and have a general sense of which habitats, ecosystems and species are protected. However, it is clear from the results of the bioblitzes that many species are not captured in a general survey; further work is needed.

Seabird Nesting

David MacKinnon (mostly unpublished data but also in Cameron and Mackinnon (2008)) began collating and assembling existing data on seabird nesting in protected areas in the mid-2000s. MacKinnon also began his own systematic surveying of protected off-shore islands. Some of these surveys were done in partnership with various agencies including NS Natural Resources, Environment and Climate Change Canada and NS Nature Trust. Birds surveyed included cormorants, terns, eider ducks, storm petrels, gulls and puffins. Many species are of conservation concern and include Atlantic Puffin (*Fratercula arctica*), Great Cormorant (*Phalacrocorax carbo*), Arctic Tern (*Sterna paradisaea*) and Roseate Tern (*Sterna dougallii*).

These data provide a baseline against which to monitor changes over time, and aid in the planning of these protected islands.

ECOLOGICAL SYSTEM PLANNING

Ecological Land Classification

The primary purpose of Wilderness Areas and Nature Reserves in NS is to protect natural biodiversity including all the elements of genes, species and ecosystems. The scientific approach to capturing biodiversity within protected areas in NS has been largely with a coarse filter – fine filter method (Cameron 2017). The coarse filter approach has been to capture the variety of ecosystems present in each Natural Landscape. In order to provide a digital mapping tool to apply a coarse filter approach, Cameron and Williams (2011) completed a geographical information system (GIS) based ecosystem classification system (ECS) for NS Environment and Climate Change. The classification system integrated aspects of existing forest management classification system (Neily *et al.* 2017) (https://novascotia.ca/natr/forestry/ecological/ecolandclass.asp) and the national vegetation classification system (Langendeon *et al.* 2014) (http://cnvc-cnvc.ca/). Principles of landscape pattern that were incorporated into the system include: (1) hierarchy; (2) abiotic and biotic factors; (3) use of more abiotic factors at coarser spatial scales and more biotic factors at finer spatial scales; and (4) use of vegetation only at the finest scale. The ECS builds on previous work, allows for integration of existing landscape classification systems, and establishes methods that can be applied for a variety of landscape planning issues in other regions.

Cameron (2021) tested the assumptions of the ECS that abiotic and biotic factors are predictors of biodiversity distribution across the landscape. A preliminary exploratory analysis was done using a subsample of the biodiversity plot data (described above) (n=44) to test how well ECS attributes predict species richness. The biotic attribute (vegetation type) was the only significant predictor of species richness and the abiotic factors (soil drainage, soil texture, topographic pattern) were poor predictors of species richness (Cameron 2021). Abiotic factors are more enduring features compared to biotic factors and thus can form a framework to build an ECS. However, the analysis by Cameron (2020), although preliminary, does suggest the need for inclusion of biotic factors if an ECS is used to predict distribution of biodiversity on the landscape.

Gap Analysis

Using the ECS from Cameron and Williams (2011), a gap analysis was done to determine how well the variety of ecosystems were captured in existing or proposed protected areas (Cameron 2014). Representation was based on how well a particular protected ecosystem captures the expected number of species and ecosystem elements in the landscape. Representation was considered complete when 90% of the expected number of species were present in a protected ecosystem, and good when 75% to 89% of the expected number of species were present. Percentages for completeness of representation were based on a species-accumulation curve, following methods described by Desmet and Cowling (2004) and using data for Nova Scotia plant species (Cameron 2021). The result is a GIS based layer which identifies which ecosystems across the province are "complete" for protection (90%), which are "good" (75 to 90%), and which are less than complete (Fig 3). Results suggest

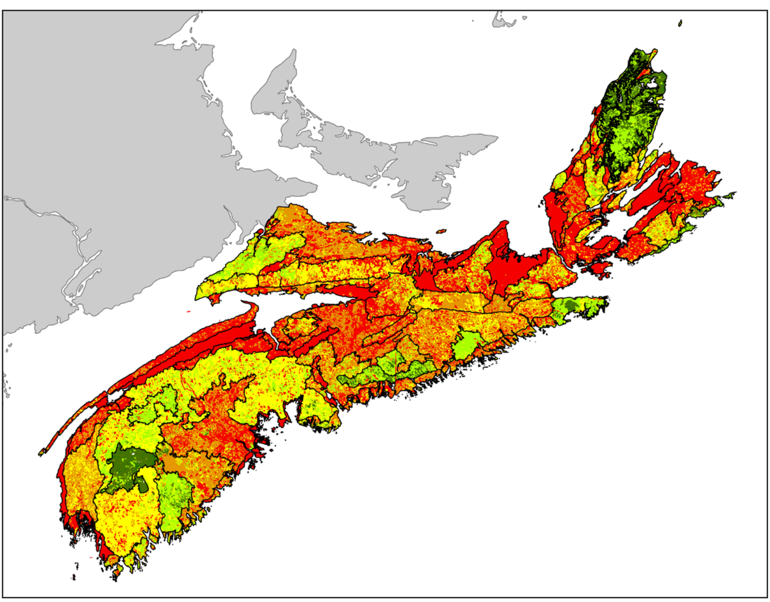

Fig 3 Gap analysis map of Nova Scotia. Redder colour indicates ecosystems with decreasing proportion within protected areas and darker green indicates increasing proportion within protected areas.

that there are large gaps in many landscapes and several landscapes have no representation in existing or pending protected areas.

Conservation Planning

The Colin Stewart Forest Forum (2009) was the most involved and extensive protected area planning process involving PAE. The Forum was established by multiple stakeholders, including forest industry, NGOs and the provincial government, in an effort to identify the most important areas for protection for the conservation of biodiversity. Cameron (2017) outlined the scientific criteria and systematic process for finding areas of highest conservation concern, which involved three main steps. Step one identified 3 types of potential areas, which involved use of remote data, including satellite imagery, aerial photographs, GIS remote data, expert input and existing field data from a variety of sources (Fig 4). Step 2 involved scoring each patch based on 5 systematic criteria. The final step involved selecting the most promising areas using decision trees (Fig 5).

National and International Standards

Increased global initiatives to help reduce biodiversity loss were sanctioned by Parties of the Convention on Biological Diversity by adoption of the Strategic Plan for Biodiversity 2011–2020 and the

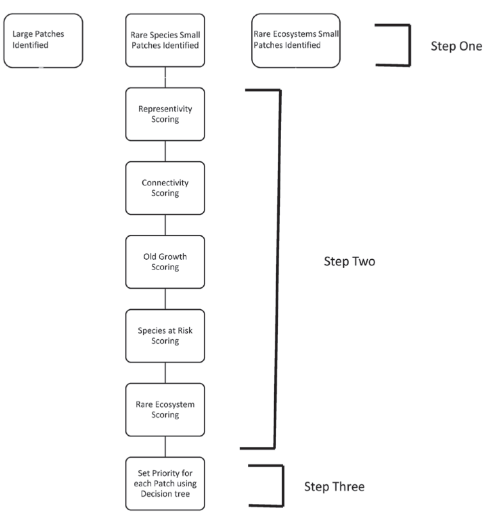

Fig 4 Process for using science to identify, score and set priorities for patches for potential protection in Nova Scotia.

A

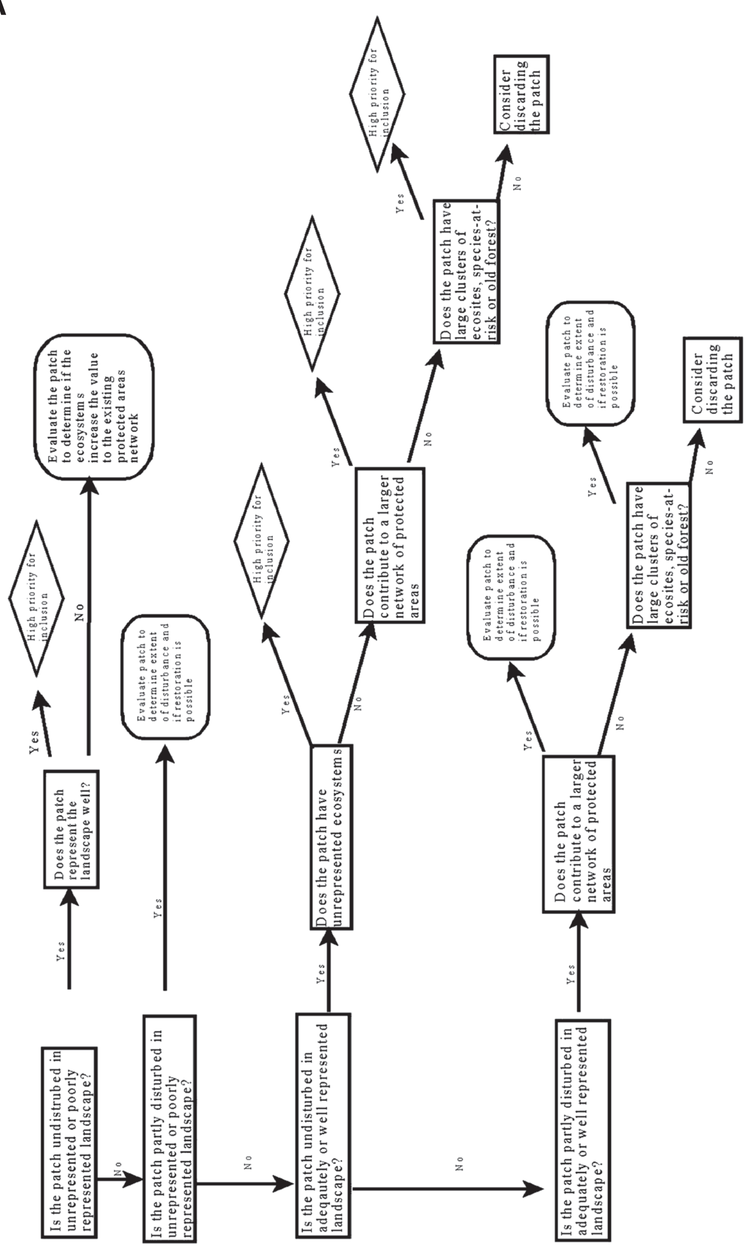

Fig 5A **Decision trees used in setting priorities for protection for large patches (A – contiguous areas larger than 1000 ha) and small patches.**

B

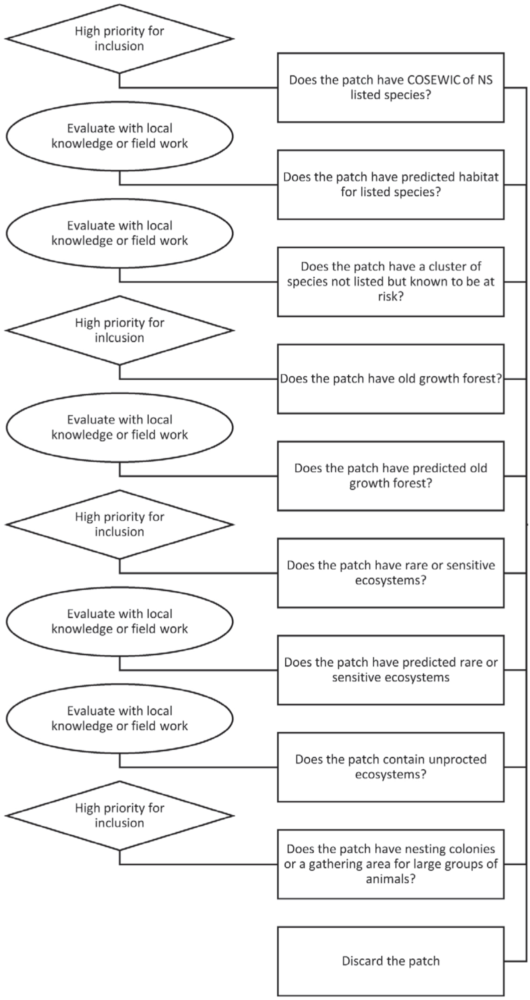

Fig 5B Decision trees used in setting priorities for protection for large patches (B – areas less than 1000 ha).

20 Aichi Biodiversity Targets in 2010. However, Aichi Biodiversity Target 11 stated that both protected areas and 'other effective area-based conservation measures' (OEABCMs) could be used to meet national protected areas targets. This presented a significant reporting and identification challenge in determining what counted as OEABCM (MacKinnon *et al.* 2015). In response, the Canadian Council on Ecological Areas (CCEA) developed a guidebook and

decision support tool for Canada (CCEA 2018) and for the Pathway to Canada Target 1 initiative (2021). Following this Canadian initiative and its' presentation as a case study (MacKinnon *et al*. 2015), the International Union for the Conservation of Nature (IUCN) established a task force to develop guidance internationally (Jonas *et al*. 2018). The result of the task force was the publication of an international guide for recognizing and reporting other effective, area-based, conservation measures (IUCN 2022). Significant contribution from PAE staff was made on the national and international projects (MacKinnon *et al*. 2015, Jonas *et al*. 2018).

LONG-TERM MONITORING

Transect

Cameron (2020b) examined the statistical power of using transect data for long-term monitoring. He found that for species that had high temporal variation or small spatial variation, a relatively small number of biodiversity plots (<20) were needed to have an 80% probability of detecting a change when it actually occurs. For species with high spatial variation or low temporal variation, more than 100 plots were needed to have an 80% probability of detecting a change. For detecting species richness changes and for diversity indices, only six plots are needed to have an 80% probability of detecting change. The conclusion was that transect and plot data are useful for monitoring general measures of richness or diversity or for species that show a large change over time.

Lichens

PAE developed a plan for long-term monitoring of air quality and climate change using lichens (Cameron 2004a). Lichens have long been used for environmental monitoring and a number of protocols have been developed (McCune 2000). PAE initially developed an indicator set of species for use in the monitoring program so that extensive training in lichens was not required to establish monitoring plots (Cameron *et al*. 2007). The program was later expanded to capture all species of lichens within a plot, using European protocols (Richardson 1992). Sixty-five plots were established in protected areas throughout the province (Cameron 2011). Todd (2008) examined the statistical power of the lichen monitoring data and found that to detect a trend of at least 10% (positive or negative) in lichen diversity in one plot, sampling every year for 13 years, or every third year for 22 years, is required. To detect a difference between two regions, the required sample size was calculated to be 38 plots. Both Todd (2008) and Cameron (2010b) found that the lichen data suggested that generally, NS had good air quality with the exception of the major urban and industrial centres, e.g., Halifax, Port Hawkesbury and Sydney.

In 2009, PAE partnered with Acadia University to study mercury (Hg) levels in the province using lichens in the genera *Usnea* and *Hypogymnia* (Saunders *et al.* 2016). Collections were made at all permanent lichen monitoring plots in protected areas. This was later expanded to 165 collections from around NS. Concentrations of Hg were highest around Kejimkujik National Park and Tobeatic Wilderness Area, which is consistent with high concentrations observed in biota in previous research (Evers *et al.* 2005, Little *et al.* 2015). Concentrations of Hg were not significantly different between protected areas and the surrounding landscape (Saunders *et al.* 2016).

An additional 12 metals were also sampled and collection sites increased to 190 (Klapstein *et al.* 2019). The data support the hypothesis that Hg in lichens is from historical gold mining and ongoing long-range transport and diffuse emission patterns, rather than localized pollution sources. Metal concentrations were shown to have median values that are similar to other remote regions such as the Antarctic; however, the maximum values for some metals (e.g. lead, cadmium) were substantially higher than other remote areas. This research demonstrates the usefulness of lichens as biomonitors and provides a baseline for future monitoring efforts.

CLIMATE CHANGE

Contributions to Adaptation and Mitigation

There is currently substantial research and modelling evidence that protected areas can significantly contribute to mitigation of, and adaptation to, climate change effects on natural systems and human infrastructure (Cameron 2012). In terms of adaptation, Cameron (2012) provides several examples from NS. An example of safe-guarding drinking water is the increasing area of municipal drinking water watersheds that are within, or partially within, protected areas in Nova Scotia including Antigonish, Amherst and Halifax. Additional ecosystem services that protected areas can help maintain during climate change are nursery grounds for marine and freshwater fisheries, pollinators and flood protection. The Gully, for example, is a marine protected area off the coast of Nova Scotia that provides a nursery ground for several fish and invertebrate species (Rutherford and Breeze 2002). Protected areas can continue to play a vital role in protecting biodiversity in the changing climate in Nova Scotia. The only krummholtz-boreal forest in the province is almost entirely within Cape Breton Highlands National Park, with disjunct portions in Margaree River and Pollets Cove Aspy Fault Wilderness Areas (Cameron 2004b). Species at the northern extent of their range in Nova Scotia include many species of coastal plain flora found in the south-western portions of the province. These coastal plain plants are distinct in Nova Scotia from the coastal plain of the eastern US. Many of these species are rare in Nova Scotia and susceptible to human impacts (Davis and Browne 1996). Northward migrations of coastal plain flora in a warming climate could be facilitated by protected areas which could act as travel corridors and stepping stones. Without protected areas, these rare plants could be in danger from human activities (Cameron 2012).

The Canadian Parks Council – Climate Change Working Group was tasked with identifying areas where protected areas could become “natural solutions” to climate change. PAE, as part of this group, provided specific examples from NS, along with other provincial and territorial jurisdictions across Canada (Canadian Parks Council Climate Change Working Group 2013). Mitigation examples from Nova Scotia included carbon sequestration and storage in protected areas, and corridor connectivity in the Chignecto Isthmus between Nova Scotia and New Brunswick.

Carbon Modelling

To get a better understanding of how protected areas in NS could contribute to mitigating the effects of climate change, carbon storage and sequestration modelling was done for a number of protected areas. Initially, four protected areas were modeled for carbon storage over a one-hundred-year period using the Canadian Forest Service – Carbon Budget Model (CFS-CBM) (Kull *et al.* 2006). Results were compared to forest product harvesting scenario carbon modelling as a base case. Continued protection over the next hundred-year scenario maintained higher carbon stocks than harvest scenarios in all modelled areas. Although the four modeled Nova Scotian protected areas represented a significant current stock of carbon (1.04 x 107 t C), there was only about a 15% increase in long-term carbon sequestration potential (Morton *et al.* 2010).

Cameron and Bush (2016) developed a Nova Scotia specific model for estimating carbon storage and sequestration over time). The model was run on existing protected areas comprising 514,000 ha and 245,000 ha of proposed protected areas under three scenarios: (1) protected status; (2) forestry management which maximized timber yield; and (3) forestry management with environmental considerations. The model suggested that 112 million tonnes of carbon are stored in existing and proposed protected areas and if protected, these forests would sequester carbon over the next 130 years. If the proposed and existing protected areas were managed for forestry, they would become a carbon source for the next 130 years for both maximum yield and forestry management with environmental considerations scenarios. There was a decrease of about 2 percent and 11 percent in total amount of carbon stored over 130 years for forestry management with environmental considerations and maximum yield scenarios, respectively. Frequent disturbance from clear-cut harvesting likely increases decomposition of organic matter in the forest, which exceeds carbon sequestration by regrowth (Cameron and Bush 2016). Both modelling studies indicated only a modest increase in sequestration of carbon over the study period, for protection designation, but the greatest advantage of protected areas is the greater certainty in land use and in maintaining the current and future carbon store. The carbon sequestration modelling in NS protected areas received an international award from Climate Change Impacts and Responses Organization in 2015, and results were presented at a conference in Iceland in 2014 (Cameron and Bush 2016).

Climate Adaptation Planning

While protected areas can provide optimal settings in which adaptation and mitigation can take place, managers and planners also have to ensure conservation of resources that they are managing. Hennigs (2014) reviewed relevant literature on protected areas management systems for integrating climate change into protected areas management planning. She presented the most promising frameworks which could be incorporated for a Nova Scotian situation and how they could be adopted or modified for the province. Conservation objectives might have to be re-formulated, stressing a holistic ecosystem approach with a long-term perspective. She identified the non-linear dynamics of ecosystems and also that humans should be considered as part of the ecosystem. Furthermore, the focus of conservation efforts should be to protect functions and services that ecosystems provide, instead of concentrating on individual species, because this will be more sustainable in the long run. The approach of conserving the "stage and not the actors", i.e., focusing on physiographic instead of bioclimatic representation, may be important for conservation, as well as giving connectivity a central role in all conservation efforts. By considering several climate scenarios and determining several adaptation options, the Adaptation for Conservation Targets (ACT) framework by Cross *et al*. (2012) will lead to the implementation of actions most defensible under most climate scenarios. This framework has already been applied across the United States, and it was also recommended by several experts contacted during the research for the Hennigs study. A workshop with natural resource professionals and scientists would be needed to begin implementing the ACT framework in Nova Scotia. The ACT has 4 steps: (1) Identify conservation features and management objectives (e.g. maintain viable population of a species at risk); (2) Assess effects of plausible future climate scenarios; (3) Identify management actions; and (4) Prioritize management actions.

With the ACT process in mind, PAE used localized climate change forecasts and ecological susceptibility to climate change for each protected area under management in order to identify and prioritize protected areas for possible management intervention or special attention in the light of a changing climate. Each individual protected area was first ranked on susceptibility to climate change based on 3 criteria: (1) Presence of species at risk (SAR) with susceptibility to climate change; (2) Percentage of protected area with boreal or arctic/alpine ecosystems; and (3) Presence of low elevation and erosional coastal ecosystems, e.g. salt marsh, beach, dune, lagoon, estuarine flat, erosional sea bluff (R.P. Cameron, unpublished data). Downscaled climate projections were produced from over 40 global climate models (IPCC 2013) for five geographical regions in NS. These climate forecasts were then overlaid on each protected area to produce a climate projection for each protected area (ClimAction Services 2017). The climate projections were then compared with climate susceptibility rankings to provide an overall ranking of climate change risk for each protected area (R.P. Cameron, unpublished data). These overall rankings will allow planners to target vulnerable areas for specific management interventions as needed.

In 2017, PAE as part of the Canadian Parks Council – Climate Change Working Group, developed a Climate Change Adaptation Framework for Parks and Protected Areas, which guides planners and managers through a five-step adaptation process. The framework was adopted by Parks Canada using two-day workshops. Eleven workshops were held between 2017 and 2019 at Parks Canada sites in the Yukon, Quebec, Manitoba, Alberta, Nova Scotia, British Columbia, Newfoundland, and Ontario. Input from the workshops was integrated into the approach which contributed to the development of tools and guidance for each phase of the process (Nelson *et al*. 2020). The process can be used by protected areas planners in any jurisdiction, level of government or other organization.

SPECIES OF CONSERVATION CONCERN

Protected areas in NS provide habitat and protection for populations of many species at risk (Cameron 2004b). In some cases, protected areas were established to protect known populations or habitat for SAR. In other cases, SARs are captured incidentally when representative ecosystems are protected.

Transects

Transect and plot sampling as described above is a systematic protocol used in Wilderness Areas and Nature Reserves that allows calculation of densities and population numbers of species of conservation concern (Cameron 2019). Two hundred and twenty-two occurrences of species of conservation concern were recorded between the period 2002 and 2017. Nine bird species and 19 plant and lichen species were recorded 2 or more times. Densities for bird species ranged from 0.023 individuals per km of transect (± 0.012) for Boreal Chickadee (*Poecile hudsonicus*) to 0.727

individuals per km (± 0.007) for Eastern Wood Pewee (*Contopus virens*). Plants densities ranged from 0.02 individuals per km (± 0.01) for Round-Leaved Orchid (*Platanthera orbiculata*) to 27.1 individuals per km (± 10.4) for Bulblet Bladder Fern (*Cystopteris bulbifera*). Most species of conservation concern were rare, with 66% being found only once (Cameron 2019). Analysis of transect data for species of conservation concern demonstrate the rarity of this group of species. It also demonstrates the important role of protected areas in providing habitat for such species.

Turtles

Researchers from Acadia University first identified the Tobeatic Wilderness Area as having potential endangered Blanding's Turtle (*Emydoidea blandingii*) habitat in 2005. Initial investigations included examining aerial photography for potential Blanding's Turtle habitat. A number of promising sites were identified with the most likely being along the Roseway River near Indian Fields and Third Bear Lake. Live trapping for turtles began in summer 2005 with 24 trap nights and 6 hours of visual searching for each of the Roseway River and Third Bear Lake sites within the Tobeatic Wilderness Area. No Blanding's Turtles were observed or trapped, however, 93 Painted Turtles (*Chrysemys picta*) were captured (Landry and Cameron 2005). In 2007, volunteers from Mersey Tobeatic Research Institute (MTRI) in cooperation with Acadia University, began searches and trapping in Mooseland Stream and Whitesand Stream in the Tobeatic Wilderness Area. Trapping continued through 2009 for a total of 728 trap nights on 3 waterbodies: Sporting Lake Stream, Whitesand Stream and Moosehide Lake Stream. Four Blanding's Turtles were found; two mature males, one mature female and a juvenile. In 2009, all turtles were radio tagged and movements monitored. It is likely that this is a very small, isolated group of Blanding's Turtles, with no close connection to any of the three main sub-populations, although no genetic work has been done to confirm this. The nearest sub- population, Kejimkujik, is over twenty kilometers to the east. There are many more areas in the Tobeatic Wilderness Area that appear to have favourable habitat and future visual surveys and trapping could lead to discoveries of other Blanding's turtles (Clapp *et al*. 2015).

Mammals

In 2008, six hair collection sites for Eastern Cougar (*Puma concolor couguar*) were established in Kejimkujik National Park. In 2009, two sites were established in the Tobeatic Wilderness Area. Sites consisted of an olfactory lure. Sample sites were checked several times a year and hair samples were collected. Between 2009 and 2014, samples were sent for DNA analysis according to standard protocols (Lang et al. 2013) to the Natural Resources DNA Profiling Forensic Center at Trent University, Peterborough, Ontario. All samples came back negative for eastern cougar (Clapp *et al.* 2017).

Wilderness Areas provide habitat for several provincially endangered mammals. The largest subpopulations of Endangered Mainland Moose (*Alces alces americana*) occur in the Tobeatic Wilderness Area and smaller populations occur in Tangier Grand and Eigg Mountain – James River Wilderness Areas (Parker 2003). PAE participated in the Mainland Moose Recovery Team between 2005 and 2014 and during this time, a Recovery Plan (McNeil 2013) and Special Management Practices for forestry and other development (NS DNR 2012) were created. Several studies on Mainland Moose were initiated, resulting in publications (e.g. Broders *et al.* 2012).

Protected Areas, including eight Wilderness Areas in the Cape Breton Highlands, provide important habitat for both Provincially Endangered Canada Lynx (*Lynx canadensis*) and American Marten (*Martes americana*). These protected areas provide functional connectivity and habitat protection (Nova Scotia Lynx Recovery Team 2006, Nova Scotia American Marten Recovery Team 2006).

Lichens

Lichen research in protected areas began with inventories for species at risk in the early 2000s, initially partnered with NS Department Natural Resources and then later with MTRI (Cameron 2004a). Survey sites were guided by habitat models which helped to narrow down large search areas (Cameron and Neily 2008, Cameron *et al.* 2011a, Pearson *et al.* 2018). With a large number of locations of lichen species of conservation concern in protected areas, PAE also contributed to authoring numerous species assessments for the Committee on Status of Endangered Wildlife in Canada (COSEWIC) which later led to their designations in Canada.

Most of these species also became listed provincially under the NS Endangered Species Act. As more data became available, population modeling was done (Cameron & Toms 2016) as well as a threat analysis for boreal felt lichen (Cameron *et al*. 2013a, Cameron *et al*. 2013b). These efforts along with those of other lichenologists (e.g., McMullin *et al*. 2008, Selva 2010, Richardson *et al*. 2011, Anderson and Neily 2012) led to the designation of a number of protected areas for, or partially for, conservation of lichens (Cameron 2020a). Eight areas representing 3405 ha were established in the last ten years entirely for the purpose of conserving lichens. In addition, over 5000 ha were established partly for conserving lichens and partly for other reasons. These eight protected areas help conserve some of Canada's most at risk and rare lichens and represent landmark conservation actions for Nova Scotia and Canada (Cameron 2020a).

Atlantic Coastal Plain Flora

Atlantic Coastal Plain Flora (ACPF) inventories were conducted on Crown land starting in the late 1990s into the early 2000s by PAE staff in cooperation with the ACPF recovery team (D. MacKinnon, unpublished data). Surveys focussed on lake, stream and river shores in southwestern NS and led to thousands of new locations for ACPF. These data contributed to an understanding of habitat and distribution of ACPF and recognition of the importance of protected areas in conservation of ACPF (Environment Canada and Parks Canada Agency 2010). These data, in conjunction with work from other researchers, led to establishment of 15 new protected areas and expansion of four existing protected areas in southwest NS, amounting to over 11,000 ha of land protected for ACPF (Nova Scotia Environment 2013).

Forest Plants

Forest dependent plants of conservation concern (FDPCC) have not been well studied in NS, with the exception of habitat specific species such as those associated with karst, floodplains or wetlands (Zinck 1998, Davis and Browne 1996). Upland forest plants of conservation concern have had little research. PAE, in a partnership with Dalhousie University and NS Lands and Forestry between 2018 and 2020, investigated locations, habitat and environmental variables associated with FDPCC (Cameron 2020b). The most significant trend for individual species was for Downey Rattlesnake

Plantain (*Goodyera pubescens*) and Hepatica (*Hepatica nobilis*), both of which were found more often in later successional stages (stand re-initiation, old growth) and older maturity classes of forest (mature to old), although this trend was not statistically significant for Hepatica (Burns 2020). Habitat models were also created for these two species, indicating important habitat variables and locations for potential new sites and suggesting more protection may be needed for these species (Hodgson 2020). To help address issues of low sample size for individual species, FDPCC were divided into 3 plant functional groups (PFG) for further analysis: (1) Upland forest orchids; (2) Upland forest sedges; and (3) Upland forest geophytes (Verheye *et al*. 2003). All three PFGs were more likely to occur in protected areas than in forest managed for other purposes (PFG3 $p<0.0001$, $n=1150$; PFG2 $p<0.0001$, $n=1275$; PFG1 $p<0.001$, $n=1455$). All PFGs were also more likely to occur in landscapes with lower road density ($p<0.001$) and lower density of clearcutting ($p<0.001$), suggesting susceptibility of FDPCC to human impacts in the environment (PFG3 $p<0.0001$, PFG2 $p<0.0001$, PFG1 $p<0.001$) (Cameron 2020b).

Piping Plover

MacKinnon (2015) assessed trends in Piping Plover (*Charadrius melodus*) counts in 33 beaches in NS between 1961 and 2014. He found significant declines in the beaches with highest human use and infrastructure including Dominion, Clam Harbour, Rainbow Haven, Lawrencetown and Conrad beaches. Beaches that did not have declining counts of Piping Plover over the study period included more remote sites and those less used by humans, such as Crow Neck, South and North Beach and Red Head Beaches. Parking lot size was the single most important variable to explain declines in piping plover numbers (MacKinnon and Cameron 2016).

RARE, SENSITIVE, VULNERABLE ECOSYSTEMS

Some ecosystems are naturally rare within the landscape, such as talus slopes within NS (Davis and Browne 1996). Rare or uncommon ecosystems often provide habitat for rare species. Cliffs provide habitat for a variety of rare mosses (Ireland 1982) and vascular plants (Zinck 1998) in Nova Scotia. Talus slopes provide habitat for Gaspé shrew (*Sorex gaspensis*) (Davis and Browne 1996). Many of the ecosystems such as wetlands and riparian ecosystems are sensitive or vulnerable to human disturbance. PAE has embarked on research and partnerships to help identify, document and inventory many of these ecosystems.

Predictive Modelling

Cameron *et al*. (2011b) created predictive models for 17 types of rare ecosystems in NS using a variety of methods. Ability of the models to correctly predict where rare ecosystems occurred was high with an overall 4.3% error (false positive). The error varied widely between ecosystem type. The error of false negatives was not calculated. Results of these modeling studies were used to predict locations of rare or vulnerable ecosystems to aid in their conservation and protection (Colin Stewart Forest Forum 2009). Since then, the predictive models have been used for a variety of purposes including forestry management, conservation projects and woodlot management planning. The results also suggest that these 17 ecosystems are rare on the landscape.

Heathlands

The most extensive work on heathlands in NS has been conducted by Dr. Jeremy Lundholm and his students of Saint Mary's University (Porter *et al*. 2020). Oberndorfer and Lundholm (2009) studied heathlands in five protected areas on the Atlantic Coast. They made three conservation recommendations: (1) Rare species do not correlate with species richness, thus, protecting areas of high richness may not capture rare species and vice versa; (2) Heathland plant community composition differs widely among areas of the province, therefore, protecting any single "representative" coastal barren will not protect the range of vegetation communities; and (3) a coastal-inland gradient and a diversity of substrate types (including exposed rock and trees) should be included in protected areas planning. Cameron and Bondrup-Nielsen (2013) examined inland and Atlantic coastal barrens in eight different protected areas and reached conclusions similar to those of Oberndorfer and Lundholm (2009). They found differences between inland and coastal heathland as well as differences between regions. Thus, protected areas need to capture representative communities from the variety of landscapes. Heathland communities were found to have greater species richness and variation in community type than previously thought. Indeed, MacDonald *et al.* (2011) in a study of lichens of Atlantic Coastal barrens found six species of lichens new to the province, including one new to North America. Cameron and Bondrup-Nielsen (2013) also found that rare plants in heathlands were not restricted to any particular community type; rather, rare coastal plants in Nova Scotia occur in a wide variety of plant communities. Therefore, targeting rare species protection is needed rather than any specific type of plant community in order to help conserve rare heathland plants.

Other unique coastal communities are the nutrient enriched vegetation communities found on Hay Island in the Scatarie Island Wilderness Area (Cameron and MacKinnon 2008). Hay Island is a major haul-out for Grey seals (*Halichoerus grypus*) during the winter, and a nesting area for Great and Double-crested cormorants, Common Eider, Leach's Storm Petrels and several species of gulls. These animals contribute significant input of nutrients through defecation and decomposition of carcasses. Five terrestrial plant community types were found on Hay Island: (1) Cobble beach; (2) Rocky shore; (3) Grassy meadow; (4) Rich wetland; and (5) Herb meadow. Cobble beach and rocky shore had few plants, being dominated by the lichens. Northern Willow Herb (*Epilobium glandulosum*) and several species of grasses made up the wetland community while Reed Canary Grass (*Phalaris arundinacea*) dominated grassy meadows. Herb meadow had the greatest species richness on Hay Island. A comparison to the adjacent island, Scatarie, which has little seabird nesting and little or no seal haul outs, reveals entirely different communities. Similar communities found on Scatarie and Hay Island include cobble beach, rocky shore, and grassy meadow, although Scatarie Island had significantly fewer species in each community type compared to Hay Island. Even soil type on Hay Island indicated high soil fauna diversity compared to Scatarie (Cameron and MacKinnon 2008).

The richness of plant species and variety of community types documented by Oberndorfer and Lundholm (2009) and Cameron and Bondrup-Nielsen (2013) may not fully describe the complexity of these coastal ecosystems. Strang (1970) described inland barrens with undulating micro-topography reflected in the distribution of plant communities. He suggested that Broom-crowberry (*Corema* *conradii*) community occurred on hummock tops, Black Huckleberry (*Gaylussacia baccata*) community occurred on side slopes, and Rhodora (*Rhododenron canadense*) community in the hollows. Cameron and Bondrup-Nielsen (2013) describe changes in coastal barren communities with distance from the water. Lichen community was closest to the water, followed by Crowberry (*Empetrum* spp.) community, then low shrub and then high shrub communities. Finer scale data collection by PAE (unpublished data) from Duncan's Cove Nature Reserve found that the undulating community variation found by Strang (1970) in inland barrens was present at coastal barrens and is overlaid on the communities found by Cameron and Bondrup-Nielsen (2013). For example, it was found that the near shore lichen community actually was comprised of crustose lichens that dominated the hummock tops and fruticose and foliose lichens that were found in the hollows. Similar changes were found for the Crowberry and shrub barrens. Further investigation is needed to determine if these changes are variations in one community type or different communities altogether. Regardless, the work suggests highly complex communities and a greater variation than was previously thought for these "barren" communities.

Red Maple Wetlands

Another little studied ecosystem in Nova Scotia is Red Maple (*Acer rubrum*) wetland. Cameron (2009) studied 28 Red Maple wetlands in 15 NS protected areas. Cameron found a high plant species richness and diversity, and high structural complexity. Two species of rare vascular plants were found, and *Sphagnum* species richness was particularly high compared to upland forest and other peatlands, and included 4 species of conservation concern. Cameron (2009) found that Red Maple wetlands make a significant contribution to the biodiversity and heterogeneity of the landscape. Red Maple wetlands are also highly lichen diverse, particularly in epiphytic cyanolichens (Cameron 2011, Cameron and Neily 2008, Neily and Anderson 2010). These wetlands provide habitat for some of the rarest and most endangered lichens in NS.

Coastal Woodlands

Jack pine (*Pinus banksiana*) – Broom Crowberry woodland is a rare community type found only in NS and occurring in the Blandford Nature Reserve (MacKinnon and Cameron 2006) and the Canso Coastal Barrens Wilderness Area (Garbary *et al*. 2006). Basquill (2004) includes this community type as part of a Jack Pine-Huckleberry-Three Tooth Cinquefoil (*Sibbaldiopsis tridentate*) community. However, it may be a separate community because of the dominance of broom crowberry in the herb layer. Broom crowberry is found only in Northeastern North America and forms rare heathland communities in New England (Dunwiddie 1990, Dunwiddie *et al*. 1996). Jack pine found in this community is the form *procumbens*, so-named because it grows with a recumbent form (Zinck 1998). Several species of plants of conservation concern have been found in this community. Although it has been suggested that jack pine and the associated communities are of wildfire origin, field investigations suggest that this community type may be naturally regenerating without wildfire (MacKinnon and Cameron 2006).

OLD GROWTH FOREST

Prior to European settlement, old-growth forest likely covered large areas of Northeastern North America (Cogbill 2000, Mosseler *et al*. 2003). However, several centuries of logging, land clearing and human caused wildfires has reduced the area of old-growth significantly (Leverett 1996). Mosseler et al. (2003) estimates that as much as 50% of the Canadian Maritime Provinces forest area was occupied by late-successional tree species before European occupation. Currently, only 1 to 5% of the Canadian Maritimes forest area has old-growth forest (Lynds and LeDuc 1995, Mosseler *et al*. 2003). D'Amato *et al*. (2009) estimates that only about 0.1% of the forested land base of Massachusetts has old-growth forest and this is likely common for most Northeastern states.

Old Forest Predictive Modelling

MacKinnon (2005) created a predictive GIS model to determine where the most likely locations are for old forest. He used forest cover GIS data to identify forest stands using tree heights and species composition data. Although commission and omission errors were present, the data became a useful tool for identifying the most likely places where older forest could occur (Cameron 2017).

Dendrochronology

Hart and Laroque (2006) collected tree cores and measured ages of trees in potential old growth forest stands in protected areas and proposed protected areas across NS. Sampling was conducted by extracting 5.1 mm cores using a standard dendrochronology increment boring tool. Tree age was then determined by counting rings using image analyzing software and a microscope. Old-growth quality was analyzed based on species distribution, age structure, presence of stumps and presence of coarse woody debris. Several old growth forests were reported at Sixth Lake, Silver Lake, Lake Rossignol and French River Wilderness Area which included the oldest reported eastern hemlock in NS.

Old Forest Scoring

Identifying old forest in the field can be challenging and NS Natural Resources developed a system to score old forest (Stewart *et al*. 2003). Criticisms of this approach have been that it tends to rely heavily on tree ages and will miss old growth forests that have younger age trees but long continuity of forest cover.

Selva (1996, 2003) suggested one approach is to measure forest continuity rather than tree age. He proposed the use of lichens as a measure of forest continuity in Northeastern North America based on previous work by Rose (1976) in Britain. McMullin *et al*. (2008) proposed another suite of lichens for assessment of old growth forest in southwest Nova Scotia. The greatest challenge with using lichens as indicators is that it requires extensive expertise and often time-consuming identifications in the laboratory. Cameron and Bondrup-Nielsen (2012) suggested using abundance and frequency of a single species that is easy to identify in the field, coral lichen (*Sphaerophorus globosus*), as an indicator of old growth coniferous forest in NS.

Another approach to assessing old forest is being developed by PAE (Cameron 2020) using plant functional groups (PFG). Presence and abundances of certain PFGs (e.g. geophytes) have been used as indicators of human disturbance in forests in Quebec (Verheyen *et al*. 2003). Cameron (2020) measured abundances of 5 different PFGs in 48 old growth forest plots and compared them to previously harvested forest plots. A statistical model was developed which predicts the probability of old growth using PFGs from quadrat data. The proposed method can be used in any type of forest (coniferous, deciduous, mixed) regardless of soil moisture or tree age.

EDGE EFFECTS

Setting aside an area for protection does not mean the area will function naturally with no human impacts. There will be many human impacts such as from climate change and air pollution. One well-studied impact of adjacent human activity on protected areas is edge effect. Activities such as road construction, forestry and agriculture can cause impacts that extend into protected areas.

Literature Search

Cameron (2007) summarized the research on known edge impacts of forestry on protected areas. Edge effects can include changes to both ecological processes and organisms within the protected area. For example, tree harvesting can affect downstream conditions of sedimentation (MacDonald *et al*. 2003) and temperature (Story *et al*. 2003) which in turn can affect downstream fauna. In terrestrial environments, tree harvesting adjacent to protected forests can affect physical parameters such as light and wind within the protected area (Chen *et al*. 1995) which in turn can affect flora and fauna. Edge effects can also include changes in biota such as establishment of invasive exotic species (Parendes and Jones 2003, Greenberg *et al*. 1997) and increased nest predation of song birds (e.g. Poulin and Villard 2011). Road construction for forest access seems particularly problematic causing geomorphic hydrologic changes which can affect organisms (Hunter 2000, Gucinski *et al*. 2001). Habitat fragmentation, road avoidance behavior and facilitation of invasive species are a few of the issues related to species (Hunter 2000, Gucinski *et al*. 2001). Cameron (2010) concluded with four recommendations for forest managers working near protected areas: (1) Retain or restore natural climax forest species composition; (2) Reduce edge contrast between working forest and protected areas; (3) Maximize protection of watercourses draining into protected areas; and (4) Plan road networks to minimize undesirable effects on nearby protected areas.

Further investigation into the research literature on edge effects of forestry was done in 2017 in a joint project with Department of

Natural Resources, Wildlife Division and PAE. Efforts were made to find studies relating to distance of edge influence into a protected forest. There was wide variability in the scientific literature with effects distance as little as 10 m for some vascular plants (e.g., Matlack 1994) and as great as 500 m for frogs (Herrmann *et al*. 2005). Few data were available from local research on edge effects. However, Cameron *et al*. (2013a) in Nova Scotia found clearcutting was affecting mortality of endangered Boreal Felt Lichen (*Erioderma pedicellatum*) within 500 m, and MacQuarrie and Lacroix (2003) found invasive plants 300 m into the forest from an edge in Prince Edward Island.

Field Study

In order to get a better understanding of edge influence in a NS protected areas context, a joint study was undertaken between Department of Natural Resources, Wildlife Division and PAE in 2018 at Cloud Lake Wilderness Area. Six transects were established which transected the edge of a clearcut into the protected area for a distance of 150 m. Song meters were placed at regular intervals to record bird songs during nesting season over 2 years (2018, 2019). Vegetation quadrats were also established at each interval. Data are currently being analyzed but disturbance-associated plant species were found up to 150 m into the forest from the clearcut-forest edge (Cameron 2021).

CONNECTIVITY

Inglis (2007) studied connectivity in southwest NS using four indicator species. She found that connectivity was relatively good within protected areas and between Tobeatic Wilderness Area and Kejimkujik National Park but low between other protected areas in the region. Since that study, a number of protected areas have been established between existing protected areas in this region which help improve connectivity. These new areas include Dunraven Bog Nature Reserve, Sixth and Coades Lakes Nature Reserve, and Shelburne River Wilderness Area (Province of Nova Scotia 2013).

Cameron (2017) assessed the contribution of the Parks and Protected Areas Plan to connectivity in the province. Effective Mesh Size (EMS), as described by Jaeger (2000), was selected as the connectivity measure which is the sum of squared habitat areas divided by total area. It was found that an increase in protected areas across the province from about 8% of the land area to about 13% of the land area increased connectivity by 25% within the province.

MacKinnon and DeGooyer (unpublished data), in working with researchers from Dalhousie University and others, were able to identify key areas that are important for maintaining connectivity in the province. These are pinch-points or narrow corridors of natural habitat where there is natural movement of animals between regions. These included South Panuke Lake and the Chignecto Isthmus. The South Panuke Lake Wilderness Area was established, in part, to aid in this important connectivity node for the province (Province of Nova Scotia 2013).

Conservation efforts by the Nature Conservancy of Canada (NCC) and PAE enabled the establishment of key protected areas in the Chignecto Isthmus to aid in the movement of animals from NB, including endangered mainland moose. NCC entitled their efforts as the Moose Sex Project in a successful effort to gain public interest and support.

At the national level, PAE staff member, David MacKinnon, participated in the Canadian Council on Ecological Areas Committee examining connectivity in Canada (Lemieux *et al*. 2021). They presented the need for connectivity in Canada, governance, law and policy, as well as a needs assessment for implementing connectivity in Canada. Several successful case studies were presented including the Halifax Green Network Plan.

RAIN FOREST

Temperate rainforests are characterized by high rainfall and relatively cool summer temperatures. Most temperate rainforests occur in the oceanic mid-latitudes, with western North America being the largest area of temperate rainforest. Other rainforests occur in Chile, western Europe, southeastern Australia and western New Zealand. Coniferous or broadleaf evergreen trees dominate most temperate rainforests, although often deciduous trees can be found (Alaback 1991). Temperate rainforests are globally rare, comprising less than 0.02 percent of the earth's land area (Della Sala *et al.* 2011). The long growing season of temperate rainforests means that they have some of the highest biomass of any terrestrial ecosystem. Temperate rainforests are biologically diverse, often with high levels of endemism (Cook and MacDonald 2001, Smith-Ramírez 2004).

Rain forests have been previously described for parts of NS (Holien and Tonsberg 1996, Thompson *et al.* 2003). PAE staff in working with Clayden *et al.* (2011) described these forests as per-humid hemi-boreal. Per-humid forests can be subject to short periods when water loss exceeds water gain but these are compensated for by longer periods of excess water in other seasons. Hemi-boreal describes the temperature-boreal transition zone found in NS. Using lichens as temperate forest indicators, Clayden *et al.* (2011) identified the Eastern Shore and parts of Eastern Cape Breton Island as rain forests of NS.

A narrow band of forest along the Atlantic coast of Nova Scotia has been continually recognized as unique. Dzikowski (1985) identified the Atlantic coast of Nova Scotia as a separate climatic region of the province. The Atlantic region was characterized as having relatively high annual precipitation, low summer and high winter temperatures. Loucks (1962) suggested the Atlantic coast of Nova Scotia as a distinct forest type within the Maritimes. Later ecological classification also identified this region as distinct (Davis and Browne 1998, Lynds and LeDuc 1995). The Atlantic coast of Nova Scotia has the coolest summer temperatures and warmest winter temperatures in the province (Davis and Browne 1996). Annual precipitation in this region is from 1400 to 1500 mm, with more than 80% falling as rain (Cameron *et al.* 2008).

More recent work by PAE helped define more clearly the zone of per-humid forests. We used five indicator lichens suggested by Clayden *et al.* (2011) and characterized the climate in the distribution area for these species using machine learning AI software BIOCLIM (Fick and Hijmans 2017). The zone of climate likelihood was plotted and indicates Eastern Shore and parts of eastern Cape Breton as the most likely areas of per-humid forests (Fig 6). The predictive value of the map needs to be verified by field surveys for indicator species in previously unsurveyed areas. This map can then be used to assess the level of protection within these unique forests and determine where gaps need to be filled for protection.

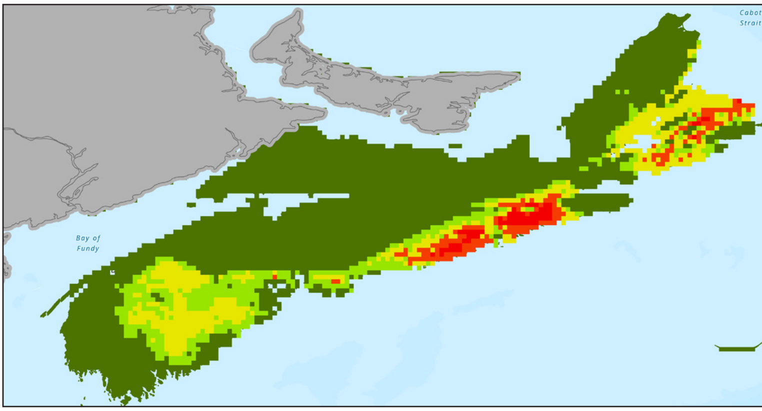

Fig 6 **Predicted area of per-humid, hemi-boreal forest using five indicator lichens in a machine learning environment.**

HUMAN USE OF PROTECTED AREAS

Motorized Vehicles

Human use of these protected areas is well known and some aspects have been documented. Negative human use has been well documented by Williams (e.g. Williams 2009, 2010, 2011, 2012). However, these are mostly inventories of human use rather than research investigations. Baker *et al*. (2004) studied the change in Off-highway Vehicles (OHV) use in Bowers Meadows and Tobeatic Wilderness Areas using aerial photography taken in 1988 and 2000. They found an overall 51% increase in OHV trails between these dates. Cameron (2016) reviewed over 200 published papers on environmental effects of OHV. He found extensive possible impacts from local soil erosion to landscape scale impacts such as animal avoidance behavior. Cameron notes the ecological need for large undisturbed Wilderness Areas and that National Parks and Wilderness Areas in NS represent the few remaining large natural areas.

Foot Traffic

Foot traffic by humans can also be cause for concern if excessive. Sora (2017) studied the human foot traffic at Duncan's Cove Nature Reserve and found damage to soil and vegetation from high use. Development of trails with resistant surfaces was suggested. Walking trails have been built in many protected areas, many of which are maintained by community groups. Some examples include

Gully Lake, Economy River, Waverley Salmon River Long Lake, Whites Lake, Tobeatic and North River Wilderness Areas. These trails have been well planned to minimize environmental impacts, avoiding rare or at risk species and habitats. Canoe routes are also established within many Wilderness Areas and include planned portage routes.

CONCLUSIONS AND FUTURE DIRECTIONS

Science in the support of managing protected areas is needed. There have been significant increases in the amount of area protected within the province over the last 20 years. For example, the Parks and Protected Areas Plan included adding four new provincial parks (960 ha), 44 new Wilderness Areas (128,760 ha), 118 new Nature Reserves (34,080 ha) and expanding 12 provincial parks (3,980 ha), 31 Wilderness Areas (77,460 hectares), and 11 Nature Reserves (4,620 ha) (Province of Nova Scotia 2013). Private land trusts have been expanding areas under their ownership and management as well. It will be important to understand where sensitive species and ecosystems occur, and how human activity within the protected areas might cause impacts. Managing human use of highly traveled areas will be needed and much of this information may come from the social sciences. Very little work to date has been done in NS with respect to social science studies in protected areas.

It is clear that changing climate is having a significant impact on natural areas. Efforts to understand these impacts and how to maintain biodiversity in a changing climate are needed. Many impacts of climate change are unforeseen, such as the establishment of invasive species. Thus, it is extremely challenging to monitor and react with timely management intervention. It is also clear that new arrangements of species in the landscape will occur resulting in novel ecosystems and communities (Root *et al.* 2003), therefore making it necessary to understand and manage for biodiversity in a dynamic way.

Protected areas can play a vital role as natural solutions to mitigating the effects of climate change. However, there is much effort needed to realize these benefits, particularly in the NS context. The limited research to date has shown great promise to help highlight protected areas as natural solutions.

A more holistic approach to species conservation is needed. Populations and habitats of species of conservation concern are often conserved in protected areas and these areas can be vital to these species' continued survival. However, an increasing number of species are being listed as being at risk as new investigations are made. For example, the number of Canadian species on the IUCN Red List of Threatened Species has more than doubled between 2010 and 2016 (Kraus 2016). Some effort has been made with a multi-species approach in the NS Lichen Recovery Team and the Atlantic Coastal Plain Flora Recovery Team (Elderkin pers. comm.) but this approach will have limitations. An ecosystem approach is another avenue that may be more holistic and achievable; more research is needed into how this might be possible. How ecosystems should be identified, what needs to be done to ensure the ecosystem conservation, and how and which species at risk will be impacted with ecosystem conservation efforts are all outstanding questions.

Large scale conservation planning within the province would benefit from further development. In particular, how protected areas can best be positioned to conserve biodiversity within multiple other approaches such as environmental assessments, SAR recovery teams, and Forestry Special Management practices, needs to be understood. Compounding the disjointed approach to biodiversity conservation are the multiple agencies involved, including NGOs, provincial and federal governments. There are a few recent examples of multi-agency, multi-method efforts, including the efforts around the Southwest and Bras D'Or Lakes Biosphere Reserves. These efforts include multi-agencies and more holistic approaches, but remain regional in scope.

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AN EXAMINATION OF MERCURY CONCENTRATIONS IN EGGSHELLS OF THE COMMON SNAPPING TURTLE (*CHELYDRA SERPENTINA*) IN NOVA SCOTIA, CANADA

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ABSTRACT

Mercury (Hg) is a potentially toxic metal that has bioaccumulating and biomagnifying properties. In egg laying animals, it can be transferred from an adult female to offspring. However, in turtles, the inter-and-intra-nest variation of Hg concentrations remains unknown. We investigated the concentration of Hg in preyed-upon Common Snapping Turtles (*Chelydra serpentina)* eggshells. The variability in Hg contamination between and within each nest was assessed. In June 2021, 368 eggshells left behind by predators were sampled from 14 nests, from three different sites in southwest Nova Scotia. Ten eggshells were randomly selected from each nest for analysis. We found no correlation between estimated number of eggs in a nest and average nest Hg concentration. Significant inter-nest variation (Hg ranging from 12.0 ± 3.85 to 172.3 ± 43.9 µg/kg) and intra-nest variability may indicate maternal transfer. The collection of the shells of freshly preyed- upon eggs is a useful non-destructive sampling technique to maintain sustainable turtle populations. Our results demonstrate the need for further investigation into the impact of Hg on temperate, freshwater turtle reproduction.

Keywords*:* mercury concentration, maternal transfer, common snapping turtle, eggshells

INTRODUCTION

Mercury (Hg) is a heavy metal contaminant that lacks any biological function but has widespread prevalence and is toxic to humans and wildlife (Scheuhammer *et al.* 2007). Aquatic ecosystems are especially sensitive to the deleterious effects of elevated exposure

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to Hg (Singh *et al.* 2011). The effects include decreased reproductive success, impaired hormone production, alteration of offspring phenotype, behavioural changes and even death (Scheuhammer *et al.* 2007, Singh *et al.* 2011). Due to its bioaccumulating and biomagnifying properties, mercury can be maternally transferred from female to offspring in eggs in many oviparous taxa (Mason *et al.* 1996). For example, female American toads (*Bufo americanus*) collected from a Hg-contaminated site transferred approximately 5% of their Hg body concentration to their egg clutches which resulted in reduced hatchling success (Bergeron *et al.* 2010). Maternally transferred Hg from eggs in hatched American toad juveniles has also been associated with reduced body size and impaired larval swimming performance (Bergeron *et al*. 2011a). In tree swallows (*Tachycineta bicolor*), Hg exposure was correlated with both decreased female reproduction and fledging success (Bergeron *et al.* 2011b).

Little is known about the reproductive effects of Hg in turtles. Turtles are commonly used to monitor Hg exposure in contaminated areas because of their ecological and life-history characteristics (Green *et al.* 2010, Hopkins *et al.* 2013a, de Solla *et al*. 2004). The Common Snapping Turtle (*Chelydra serpentina*) has potential to be a useful species for biological monitoring of environmental Hg contamination as this turtle is non-migratory with a small home range (Obbard and Brooks 1981), and is therefore suitable to monitor local contamination (Golet and Haines 2001). Common Snapping Turtles are long-lived (over 100 years in the wild, COSEWIC 2008) and apex predators, both of which make them highly susceptible to Hg bioaccumulation and biomagnification (Hopkins *et al.* 2013a).

The Common Snapping Turtle is found from Nova Scotia to Saskatchewan, and throughout the United States to the Gulf of Mexico (Conant 1975). The species is the largest freshwater turtle found in Canada and can weigh up to 30 kg (Conant 1975) with a maximum carapace length of 49.4 cm (Ernst and Lovich 2009). The Common Snapping Turtle is an opportunistic omnivore which consumes about one-third of its diet as fish, one-third as vegetation, and one-third as other organisms including amphibians, reptiles, birds and bird eggs, crustacea, and other invertebrates (Alexander 1943). In Canada, the species has been listed as being of Special Concern on Schedule 1 of the *Species at Risk Act* since 2011 (SC, c. 29, 2002) and as a vulnerable species under the Nova Scotia *Endangered Species Act* since 2013 (SNS, c. 11, s. 1, 1998).

The Common Snapping Turtle, like most turtle species, has certain life-history traits that limit its ability to adapt to high levels of disturbance (Congdon *et al.* 1994, Gibbon *et al.* 2000). Throughout Canada, the Common Snapping Turtle is still widespread and relatively abundant. However, its late maturity, extended longevity, low recruitment and requirement for long, warm summers to successfully incubate its eggs, puts it at greater risk to anthropogenic threats (COSEWIC 2008). Common Snapping Turtles are highly susceptible to road mortality, especially on roads that run through or are adjacent to wetlands (Beaudry *et al.* 2008), and forecasting the effect of interventions on an endangered population requires an understanding of the spatial scales at which threat processes operate. Road mortality is among the greatest threats to semi-terrestrial freshwater turtles due to the group's life-history traits. Female Common Snapping Turtles nest for the first time between 17 and 19 years of age (Galbraith and Brooks 1989) with an average clutch size of 25-45 eggs (Ernst and Lovich 2009). The eggs are generally laid in nests which are dug in sand or gravel banks near the water, in locations with sparse vegetation. Females exhibit strong nesting site fidelity, returning to the same site in subsequent years (Loncke and Obbard 1977, Obbard and Brooks 1981). Populations experience a high rate of predation on eggs, with nest predation rates ranging from 59% to 94% (Congdon and Breitenbach 1987). Survivorship is low for hatchlings, with only a 6.4%-23.0% survival rate, in contrast survival is 93.0%-96.6% for mature adults (Heppell 1998). Current estimates of survival rates do not take into account Hg accumulation or maternal transfer. The federal management plan includes only minimal information on the risks of mercury to the species (Environment and Climate Change Canada 2016).

Given the vulnerability of freshwater turtle populations in North America, it is desirable to find ways of conducting ecotoxicology analyses on wild populations without sacrificing live turtles or still-unhatched whole eggs (Hopkins *et al.* 2013a). There are several non-lethal methods used to sample turtles, such as: whole eggs, claws/nails, blood, muscle biopsies, shell scute clippings and eggshells. Hopkins *et al.* (2013a) found that Hg concentrations in whole eggs were strongly and positively correlated with Hg levels in female muscle tissue. The authors also found that Hg concentrations negatively correlated with hatching success, as indicated by increased egg infertility and embryonic mortality. Avian and non-turtle reptile studies show that those taxa transfer Hg and other potentially toxic elements to their eggshells (Burger 1994). Hg concentrations have been found to be higher in the contents of whole eggs than in eggshells in warm-water slider turtles (*Trachemys scripta*) from South Carolina, but trace elements were still detectible in eggshells (Burger and Gibbons 1998). Additionally, Hg concentrations in eggshells of several marine turtle species including green (*Chelonia mydas*; Jian *et al.* 2021), leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*) turtles, are correlated with Hg concentrations in local coral reef sediments (du Preez *et al.* 2018). Currently, the relationship between environmental Hg concentrations and eggshells is unknown for temperate freshwater turtles.

In turtle eggshells, the intra-clutch variation is minimal for organic contaminants (i.e., polychlorinated biphenyls, PCBs; Bishop *et al.* 1994) but the intra-clutch variation of Hg concentrations in eggshells remains unknown (Hopkins *et al*. 2013b). As a result, extrapolation from current contaminant literature for turtle eggshells is difficult because organochlorine contaminants have different physiochemical properties (such as being more lipid-soluble) to those of Hg (which binds to and accumulates in protein tissues). The maternally transferred Hg quantity may decrease as clutch size increases, as the total contaminant burden is divided among a greater number of eggs. This merits further investigation given the vulnerable status of Common Snapping Turtles in Nova Scotia. The present study assesses the variability of Hg in eggshells collected from a range of nests, in order to understand the maternal transfer of Hg between and within nests in relation to whether the nests are in contaminated sites (near natural sources of environmental Hg) in Nova Scotia. This study may be the first report on mercury bioaccumulation trends in freshwater turtles in this region.

METHODS

Sample Collection

The Common Snapping Turtle is protected by the Species at Risk Act (Canada) and the Endangered Species Act (Nova Scotia), and permission to collect eggshell remnants was granted by Nova Scotia Lands and Forestry, Wildlife Division (now called Nova Scotia Department of Natural Resources and Renewables), under a Scientific/Species at Risk Permit.

Common Snapping Turtle nests were sampled at three southwestern Nova Scotia locations in Lunenburg County: Hebb Lake, Milipsigate Lake and Hebb Mill Brook (Fig 1). Sampling was conducted in partnership with Coastal Action, an environmental NGO based on the south shore of Nova Scotia. Nest monitoring and sampling were conducted as part of their ongoing Common Snapping Turtle monitoring program. All nests were monitored daily during June 2021, and all predation events which resulted in loss of eggs from each nest were noted. Approximately 368 eggshell fragments were

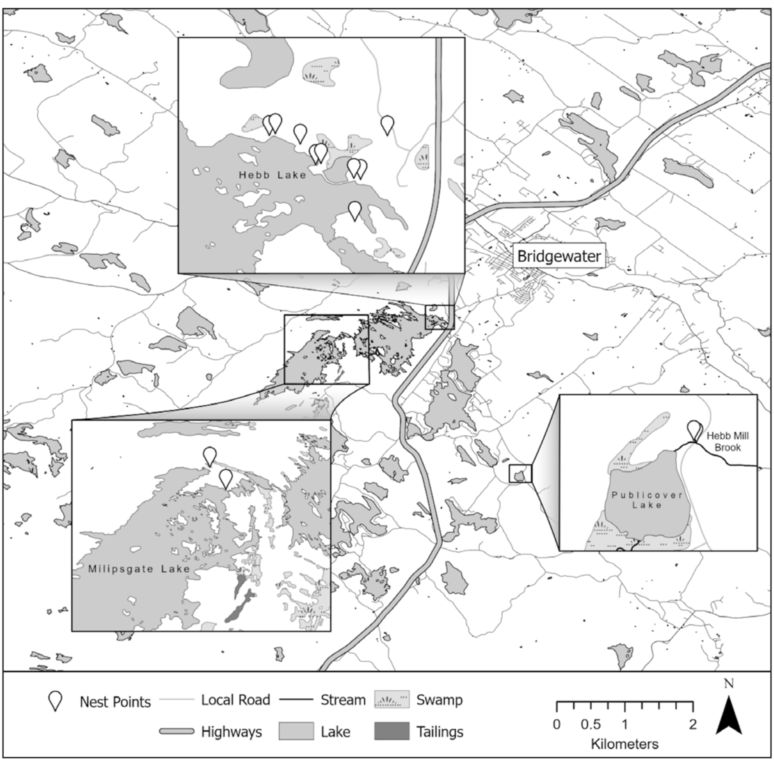

Fig 1 **Map of the three sampled nesting sites located in southwest Nova Scotia: Hebb Lake, Milipsigate Lake and Hebb Mill Brook. All sites are within 10 km of each other. Map includes historical gold mining in the Leipsigate area, which includes the Milipsigate Lake nesting site in the current study.**

collected within or in close proximity (<1 m) to nests, with collections taking place within 24 hours of the predation event. For each nest, all preyed upon eggshells were collected using latex gloves, wrapped completely in aluminum foil, individually sealed, and labelled with a nest identification number. All samples were stored in a portable cold storage chest until transferred to the laboratory freezer at Saint Mary's University until analysis.

Sample Preparation

Before analysis, eggshells were cleaned with a soft toothbrush and type-3 reverse osmosis (RO) water to remove all gravel, soil, and other external elements. Cleaned eggshell samples were air-dried for 48 h. The dried eggshells were then homogenized into fine powder using 10-vial adaptors for a Retsch MM400 mixer mill, with two 5-mm stainless steel surgical grade balls per micro-centrifuge tube (30.0 hertz/s for 2.5 minutes).

Instrumental Method and Quality Control

Total Hg (THg, µg/kg) of all samples (average sample weight 0.07 mg each) was analyzed using a Milestone Direct Mercury Analyser-80.3 © (DMA) at Saint Mary's University. Ten eggshells were selected at random from each nest to be analyzed, except for nest # MIL004, where only nine eggshells in total were collected. At the start of each analysis, certified reference materials (CRM) DORM-4 (dogfish muscle tissue from the National Research Council of Canada; certified Hg concentration: 0.412 ± 0.036 mg/kg), and DOLT-5 (dogfish liver from the National Research Council of Canada; certified Hg concentration: 0.44 ± 0.018 mg/kg) were used to validate the method and equipment. Additionally, a commercially available gardening soil supplement, GAIA Green Oyster Shell Flour (~36% calcium, gardening soil supplement), was used as a standard reference material approximating eggshell composition. Measured values (n=6) for DORM-4 were 0.392 ± 0.015 mg/kg; for DOLT-5 were 0.364 ± 0.009 mg/kg; and for GAIA were 0.002 ± 0.0005 mg/kg. Blanks were also included at the start of each analysis, and after every 10 samples. Six replicates of approximately 0.06 mg of eggshell samples were used as quality control to ensure the Relative Standard Deviation (RSD) was below 8% between measurements.

Statistical Analysis

Data were analyzed using the software Jamovi and RStudio, v.1.4.1 (*R development Core Team*). THg concentrations for each nest were plotted by site. The comparison of THg concentration between nests across all sites was assessed by ANCOVA. The variability of Hg concentrations at each site was assessed using Levene's test: homogeneity of variance. Furthermore, the relationship between approximate number of eggs in a nest and Hg concentration was determined using a correlation matrix. Significance for statistical analyses was always set at $p < 0.05$ unless otherwise noted.

RESULTS

Hg concentrations in eggshells were found to be the highest in Hebb Mill Brook nests, with averages ranging from 121.42 to 172.29 µg/kg (Fig 2). The ANCOVA also revealed a significant difference

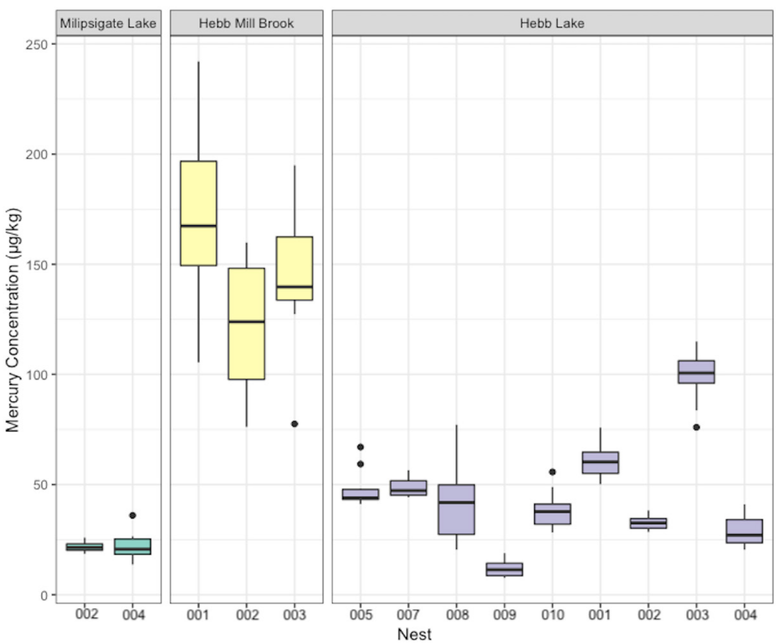

Fig 2 Mercury concentration (µg/kg) of eggshells from each sampled nest from all three study sites. Nest codes mentioned in text include ML00X (Milipsigate Lake), HB00X (Hebb Mill Brook) and HL00X (Hebb Lake).

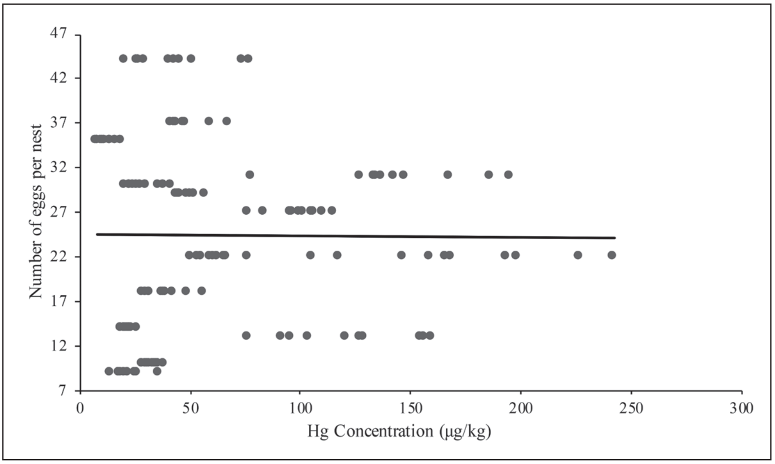

Fig 3 The approximate number of eggshells in a nest and the Hg concentration was found to have no correlation (all sites combined), r(138) = -.029, p = .737.

in eggshell Hg concentration among the 14 nests, $F(1, 13) = 73.6$, $p < 0.01$.

At Hebb Lake, Hg concentrations also varied significantly among nests ($p < 0.001$). For both Hebb Mill Brook and Milipsigate Lake, the averages of all nests at each site were considered to be equal ($p = 0.49$ and $p = 0.10$, respectively). However, these sites included three and two nests respectively, and do not hold high statistical power. Finally, the number of eggshells in a nest and the Hg concentration were not correlated, $r(138) = -.029$, $p = .737$ (Fig 3).

DISCUSSION

Average Hg concentrations of eggshells significantly differed among the three nesting sites, with highest levels of eggshell Hg at Hebb Mill Brook. In addition, we found a significant variation in average eggshell Hg concentrations among nests at Hebb Lake, and that there was no correlation between the number of eggshells within a nest (clutch size) and Hg concentration. It is clear that Hg is offloaded unequally and differently at each nest.

Maternal transfer of Hg to eggs has already been documented in several reptile and avian species. It has been found that Hg concentration in the eggs is directly influenced by the female Hg burden, which depends on habitat and diet (Ackerman *et al.* 2017, Heinz *et al.* 2010). In New York state, Hg concentrations in scute and soft-tissue samples from Common Snapping Turtles were correlated with more acidic water chemistry and atmospheric Hg deposition (Turnquist *et al.* 2011) as well as proximity to urban centers (de Solla *et al.* 2004). This leads to several possibilities which we will briefly consider here, including age and body size (larger and older turtles having accumulated more Hg over time); clutch size (larger clutches of eggs resulting in greater loss of mercury from laying adult); environmental exposure; and different bioaccumulation trends of mercury from diet.

Body size and age are often used in contaminant studies as it is presumed that older and larger individuals may have accumulated more contaminants over their lifetime. However, previous studies have found no relationship between muscle Hg concentration and body size in turtles (Golet and Haines 2001, Benjamin *et al.* 2018). Organochlorine contaminants have different physiological properties to mercury, but it has been determined that body and clutch size measurements do not significantly correlate with PCB concentrations in whole eggs. In addition, larger, older turtles, or those that lay the highest clutch size, mass, do not produce eggs that are more contaminated with organochlorine contaminants (Bishop *et al.* 1994). A published literature review of marine and freshwater turtles indicates that Hg concentrations are not correlated with body size (Benjamin *et al.* 2018).

Environmental Hg exposure for adult turtles remains a possibility. One significant potential exposure originally was expected to be historical gold mining sites. The Milipsigate Lake nesting site (Fig 1) is situated on a water body adjacent to historical gold mine tailings (Leipsigate Gold Mining District) which was historically processed using Hg amalgamation methods between 1860 and 1945 (Wong *et al.* 1999). Hebb Mill Brook is also located near a known gold-ore deposit which may have been associated with Hg amalgamation (Department of Energy and Mines 2021). Hg from historical tailings can leach into the surrounding environment through soil, aquifers, and water bodies (Wong *et al.* 1999). As a result, we expected the eggshells at Milipsigate Lake to have the highest concentrations of Hg, but this trend was not observed.

The Hebb Mill Brook site had the highest observed concentrations of Hg, and while located near a potential gold occurrence (Department of Energy and Mines 2021), other potential sources should be considered. The Hebb Mill Brook is a smaller water body, with relatively more adjacent wetland area than the other two sites which are predominately lakes. Wetlands are associated with rapid methylation of Hg and the associated increase of Hg in nearby food webs (Benjamin *et al.* 2018). Additionally, the proximity to roadways, with associated dust, tire break-down products and transport of industrial contaminants, has been observed to influence Hg levels (Lu *et al.* 2009), and the nests at the Hebb Mill Brook site were located directly on the gravel shoulder of a road. A third, but weaker, possibility for the elevated Hg in Hebb Mill Brook turtle eggshells would be that the female travelled further from contaminated sites to this nesting location. Common Snapping Turtles have non-migratory small home ranges (Obbard and Brooks 1981) with reproductive females typically travelling 2-4 km to lay eggs. However some females have been observed travelling up to 16 km (Obbard and Brooks 1980). Although, it is unlikely that three reproductive females travelled long distances from a contaminated site to lay eggs at this site, it cannot be entirely discounted due to a paucity of telemetry and tracking data for turtles in Nova Scotia.

The variation in Hg concentrations between the three sites might be associated with differences in maternal diet. While the three nesting sites in the current study were within 10 km of each other, significant variation in maternal diet, and subsequent Hg bioaccumulation from food webs, is likely. There is very little information on dietary patterns and mercury transfer in the Common Snapping Turtles in Nova Scotia. Information about diet and placement among trophic levels could be confirmed using stable isotope ratios of nitrogen and carbon of muscle tissues. In loggerhead turtles, stable isotope ratios have been observed to correlate positively with body size, indicating a trend of increasing trophic level with age (Godley *et al.* 1998). As Hg concentration biomagnifies in higher trophic levels, using stable isotope analyses on reproductive female turtles and their dietary items would allow for researchers to use non-lethal sampling methods to determine differences in diet and subsequently if diet is playing a role in elevated Hg concentrations. Diet of the reproductive females is likely an important factor in mercury bioaccumulation and maternal transfer, but remains unknown in Nova Scotia. Dietary variation compounded with habitat differences with variable Hg concentrations could play a role in Hg bioaccumulation levels for the Common Snapping Turtle adults and eggs.

This is the first study to examine maternally transferred Hg concentrations in the eggshells of temperate, freshwater turtles in Nova Scotia. For future research on turtles, the following recommendations should be considered: (1) utilize and expand upon non-lethal and non-destructive sampling techniques, including eggshells and unhatched eggs, scute shell clippings, claw clippings, blood, and tail tips; (2) additional biometric data for reproductive female at each nest are required such as diet, size, age, and even telemetry if available; and (3) data on adjacent water and sediment chemistry (including Hg) as well as landscape features (% wetlands in watershed, proximity of contaminated sites and other potential sources).

Mi'kma'ki Acknowledgement Kwe'. It is a responsibility and an honour for us to work with mikjikjik, in Mi'kma'ki, the ancestral and unceded territory of the L'nu. We carefully collected eggshells from Common Snapping Turtle nests found near E'se'katik in Sipekne'katik with no harm to the turtles. The analytical work was carried out at Saint Mary's University in K'jipuktik, Sipekne'katik. We hope our data and the results will contribute to the continued recovery of all mikjikjik populations across Mi'kma'ki. Wela'lioq.

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BOOK REVIEW

***Urban Lichens: A Field Guide for Northeastern North America.* J. L. Allen & J.C. Lendemer. 2021. Yale University Press, New Haven and London. 158 pp., 121 colour photographs and illustrations. Flexibound. ISBN 9780300252996.**

Lichenologists tend to concentrate their lichen hunting in interesting rural habitats, and most of the species found in field guides are those that occur away from busy habitats in populated places. This handy and well-thought out guide to urban lichens reminds us that there is indeed quite a variety of lichens to be found in densely populated cities. The guide's range is the northeastern US megalopolis, and the large Canadian cities of Ottawa and Toronto, with an acknowledged New York City bias. It covers approximately sixty species in detail. There are suggested habitats to explore in any northeastern city that are relevant to Halifax and urban areas in Atlantic Canada, as well as specific locations for lichen hunting in New York City.

Urban Lichens is a comfortable size, 8x5 inches (21x12 cm), has place-marking flaps back and front, and at 9.75 ounces (270 g) is light and easy to carry. Each described species has one or more photographs to accompany it, along with a species description, where to find it, and notes that include potential lookalikes. All of the species photos have either a coin or a Metro-card (a train pass the same size as a credit card) as a size reference. The photographically illustrated glossary is very useful for a beginner, though some unfamiliar yet germane terms are missing, *e.g.*, leprose, fibrils.

Most of the introductory material on lichens, covering their structure, lifestyles and uses, is aimed at making a guide that is "accessible to everyone and anyone who might be interested" in lichens. Indeed, the conversational tone and clear descriptions are well suited to that end. Yet there are sections that, given an interested but largely untutored reader, should have started with the simplest most visual concepts rather than the most complex. For example, the actual progression of lichen reproduction is somewhat complicated and does not make the easiest reading. For the novice, reading about sexual reproduction (fungal spores finding a compatible alga), apothecial shape and colour, etc., would be easier to grapple with before launching into the complicated interactions of asexual reproductive processes and structures involving pycnidia and conidia, which are not usually as obvious on the lichen's surface.

The authors make some statements about lichens that might more accurately have been modified by the addition of "most" or "generally" or "in many cases". For example, in the section 'The Lichen Lifestyle: Basic Biology and Identification' on p. 3, the description of foliose lichens reads: "In foliose lichens the algae are kept in a single layer close to the upper surface…". While there may not be many cyanobacterial jelly lichens in urban areas, saying "In most foliose lichens" at the start of the sentence would be more accurate without confusing the beginner, who most probably will not care about the exceptions. There is also the statement (p. 3) that the upper and lower surfaces of foliose lichens are different colours. While technically that could be the case, the difference in colour for *Physcia millegrana* and *Physcia adscendens*, for example, is not obvious. Again, a simple modifier would be more accurate.

Also, there may well be "thousands of chemical compounds that are unique and occur nowhere else in the natural world" as the authors assert on p. 9, but surely "hundreds" or "many hundreds" is a more accurate estimate?

The species pages helpfully show a broad view of each lichen with a magnified insert of details that help identify it when the lichen's features are small. This reviewer was unable to find mention in the text of the need for a hand lens or magnifying device to see the details. This omission is surprising, since for those just starting to look at lichens, the often tiny details are crucial for identification and may not be obvious to the naked eye. Closer close-ups would have benefitted the new observer so that the difference between *Caloplaca feracissima* and *Caloplaca flavocitrina*, both yellow and easy to spot, would be more distinct, even though the verbal details in the descriptions are certainly adequate enough.

It is unfortunate that the colour reproduction is not a bit brighter and sharper. One example is the photo of Common Greenshield (*Flavoparmelia caperata,* p. 93), which does not display its recognizable-from-a-distance yellowish colour, more adequately presented by the photo of Rock Greenshield (p. 92) on the facing page. The authors do suggest that urban lichens can look somewhat different in cities than the very same species does in a rural habitat.

Yet, the examples of usnic acid's yellow-green colour do not stand out much in contrast to the colour of other chemical compounds such as atranorin (p. 9). The photos of organisms that might be mistaken for lichens are handy, but the photos are not crisp and bright enough to be really helpful.

A key to the species should be easy to use. The authors offer an easy to understand description of what a dichotomous key is at the beginning of the section, for those who have never used one. But having done that, they fail to mention that if a couplet brings the reader to a lichen name in brackets, it is referring to a species that is not described in the book. As an example, couplet #7 offers the reader *Xanthomendoza fallax*, which has its own species page and [*Xanthomendoza weberi].* The latter appears only in the list of lichens found in NYC. It is also absent from the index. To add to the confusion, Section 3, On rock, has a choice (#8) of *Candelaria concolor* or *Squamulea subsoluta*. There is no species page for the latter, it is not in the index, nor is it on the list in the section called Lichens of New York City: The Complete List. A beginner might well scratch his or her head.

These few criticisms do not diminish the usefulness of *Urban Lichens*. To date, there has been a gap in the popular literature about lichens in urban settings. Despite its shortcomings, this small volume should encourage interested city dwellers anywhere in the northeastern US and Canada to have a go at seeing and identifying the variety of lichens around them.

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Proceedings of the Nova Scotian Institute of Science (2022)
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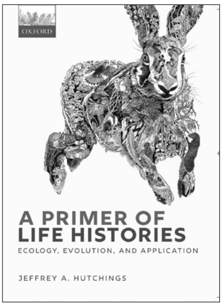
BOOK REVIEW

***A Primer of Life Histories. Ecology, Evolution, and Application*. J.A. Hutchings. 2021. Oxford University Press, Oxford, UK: 226 pp. ISBN 978-0-19-883987-3 (hbk.)[1]**



"*Embryo to egg to larvae to adult. Seed to seedling to later vegetative, flowering and pollination stages.*"

The concept of *life cycle* was once interchangeable with that of *life history*. But as author Jeffrey A. Hutchings[2] explains in A Primer of Life Histories: Ecology, Evolution, and Application, at the turn of the twentieth century, the life history of species took on a broader meaning. Nineteenth century learnings from Charles Darwin's and Ernst Haeckel's theories of evolution and Georg Mendel's work in genetics catapulted the concept of life history into bold new territory, extending eighteenth-century understandings of life history as descriptive summaries of species development.

Hutchings says it was Ronald Fisher's work in 1930 that "marked a pivotal turning point in the development and application of life-history theory." (p 3) Fisher combined existing concepts of evolution and *natural selection* (from Darwin's *On the Origin of Species*, the evolutionary process whereby organisms better adapted to their environment survive and produce more offspring) to further deepen understandings of life histories as "probabilities of survival and the rates of reproduction at each age in a lifespan." (p. 4).

But Fisher's work was mathematical in nature and while it was ground-breaking, its focus on probabilities likely delayed ecological perspectives informing how we now define life history. *Ecology* is the branch of biology that considers how organisms relate to one another and their environment. This is where Hutching's book

[1] This review was originally published at atlanticbooks.ca by Atlantic Books Today on March 23, 2022. It is republished with permission.

[2] Dr. Jeffrey A. Hutchings, a highly distinguished fisheries biologist and Professor at Dalhousie University, Halifax, NS, sadly passed away in January, 2022, at his home in Halifax, NS at the age of 63.

becomes particularly poignant, providing an overview of ways to understand the vulnerability of species to extinction, exploitation, and climate change.

If extinction assessments can be dated from the 1960s… and fishing vulnerability assessments from the 1990s… the twenty-first century has borne witness to vulnerability assessments of species to climate change. (p. 163).

Hutchings' work draws heavily on *fisheries conservation biology*, a field which he says emerged during the decade of globally prominent population collapses in the 1990s. Hutchings credits marine biologist Daniel Pauly for coining the name of the field in an obituary of one of the field's founders (and Hutchings' close colleague), Ransom Myers. Pauly defined the discipline as "devoted to identifying exploited fish populations and species threated with extinction, and suggesting measures for rebuilding them, along with the ecosystems in which they are embedded" (Pauly, 2007 as cited in Hutchings, 2021 p. 161).

Hutchings made his mark in this field becoming prominently known for his influential research on Northern cod (a critically depleted population of Atlantic Cod in the North Atlantic Ocean). His work on the evolutionary ecology of fish has influenced sustainable fisheries policies, sourcing of sustainable seafood and recovery of species at risk and led to his recognition as the recipient of the 2017 A.G. Huntsman Medal for Research Excellence in Marine Sciences.

Over his career, Hutchings held many titles and earned many accolades, but in summary, he was a Professor of Biology and Killam Memorial Chair at Dalhousie University and held appointments at the University of Oslo, Norwegian Institute of Marine Research, University of Agder, and University of Jyvaskyla. Hutchings was also a Fellow of the Royal Society of Canada and the Norwegian Academy of Science and Letters, and. co-founder of the Canadian Society for Ecology and Evolution.

In *A Primer of Life Histories*, Hutchings recounts how the International Union for Conservation of Nature (IUCN) led efforts to rectify the low number of assessed marine species. At the time, plants and animals at risk were gaining recognition, but marine fish were left behind.

Why? "The fly in the ointment was that many of these fish species were commercially valuable. Disagreement was inevitable.

It often is when conservation and commercial interests collide," writes Hutchings. (p. 154).

The IUCN, created in 1964, today remains at the global forefront of species risk assessments and protection writes Hutchings (he points to the iucnredlist.org, the world's most comprehensive information source on the global extinction risk status of animal, fungus and plant species). As Hutchings writes, the IUCN's work to assess marine fishes came at a time when "the world had recently borne witness to several biologically, ecologically, and socio-economically devastating fishery collapses" (p. 154).

The most prominent example, says Hutchings, was the collapse of Atlantic cod in the North Atlantic Ocean in the early 1990s. To describe the magnitude of the cod collapse, Hutchings writes:

[T]he collapse of Atlantic cod represents the greatest numerical loss of a vertebrate in Canada… [having] declined more than 90 per cent between the early 1960s and the early 1990s and, for all intents and purposes, remains at the same depressed level today. Numerically, this was a reduction of between 1.5 and 2.5 billion breeding individuals. By weight, this is roughly equivalent to 27 million humans. (p. 175).

As Hutchings explains, historical catch estimates show cod was sustainably fished for centuries at levels of less than 250,000 tonnes annually. Hutchings and Myers would show that catches exceeded 800,000 tonnes in 1968, mostly spurred by new and unregulated technology (*factory-freezer trawlers*, massive fishing vessels that haul trawls or nets along the ocean floor, then process and freeze 'cod blocks' on board the vessel).

The Canadian government began enforcing annual fishing quotas in the late 1970s, but much of the damage to cod was, by then, already done. In 1992, the Canadian government shuttered the commercial cod fishery. While a small commercial ('stewardship') cod fishery reopened in 2006, the *cod moratorium* remains in effect today.

"The most sustainable harvests today tend to be those blessed with the greatest amount of data," writes Hutchings (p. 176), arguing the "gold standard" of data would include: information on the numbers of individuals at each age, the natural and harvest-induced probabilities of surviving from one age to the next, and the numbers of offspring produced by the average individual at each age.

Not surprisingly, this gold standard exists for few species or populations… [and] this makes it challenging to determine harvest or catch levels that are sustainable, i.e., able to be maintained at the same levels for the foreseeable future (p. 176).

Hutchings didn't know it, but once again, cod would prove to be the best of the worst examples to make his point. In March 2022, the Canadian government announced it would not undertake this year's annual cod stock assessment due to its aging marine research fleet. That's despite the federal government's commitment to rebuild the imperilled species, which today remains in the critical zone.

Globally, the aspiration of *sustainable development* was spearheaded by a 1987 UN report produced by the World Commission on Environment and Development, writes Hutchings, and today, concepts of sustainability permeate government policies, regulatory frameworks and laws. Sustainable fishing practices are further embedded in jurisdictional tools and espoused in the UN's Sustainable Development Goals (SDG 14: Life Below Water). As Hutchings notes, these tools and policies will require continued adaptation to better understand and respond to climate change – for example, through combining information related to sensitivity, exposure, and capacity for species to adapt to climate via applying climate-change vulnerability assessments).

A Primer of Life Histories was published in December 2021 by Oxford University Press and is available in hardcopy and paperback. The primer is designed for readers from a broad range of academic backgrounds and experience including graduate students and researchers of ecology and evolutionary biology. It will also be useful to a more applied audience of academic or government researchers in fields such as wildlife biology, conservation biology, fisheries science, and the environmental sciences. The primer offers hundreds of examples from every kind of species, as outlined in the book's Taxonomic Index, as well as fittingly signalled by the book's cover, which features a species-infused hare by Cornwall, UK artist Jon Tremaine.

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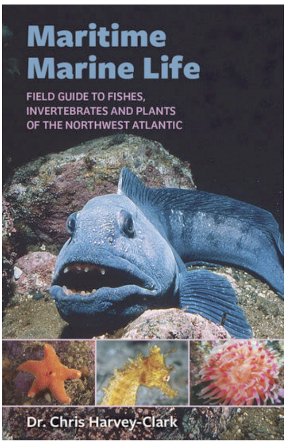
BOOK REVIEW

***Maritime Marine Life. Field Guide to Fishes, Invertebrates and Plants of the Northwest Atlantic.* C. Harvey-Clark. 2021. Meisterworks Publishing, Timberlea, NS. 96 pp.**



This superb little field guide is a "must read- must possess" for the keen amateur marine biologist and walker of beaches and coastlines. The author is an intrepid and well-known local diver, photographer and documentary film maker; he and many others contributed to the information and superb photos.

The book has a small format, hence is light and easy to pack for the field. After an informative introduction to seashore biology, oceanography of the NW Atlantic region, and taxonomy, the guide describes a range of marine plants, invertebrates, chordates (tunicates, fish) and summer visitors (finfish, other species, turtles) that are found along the shores and in the waters of Maritime Canada. It is beautifully illustrated and has a paragraph on each species which includes a scientific name, description, location and range. The book also includes a useful reference list and an index.

I was especially intrigued by the section on our summer ocean visitors, co-authored with Sarah Burko. Some animals are swept in on eddies from the Gulf Stream offshore (e.g., Portuguese Man o'War; the Chesapeake blue crab now well established in the Gulf of Maine; and 18 species of finfish). Other species are common migratory visitors from the Caribbean, such as the loggerhead and leatherback sea turtles. Especially noteworthy are the amazing images of the Great White Shark, the presence and migration of which are now studied intensively in our waters.

This field guide should find much use by residents of Nova Scotia and visitors alike. It will contribute to their knowledge of the many species inhabiting our coastal waters, and above all, add to their enjoyment of knowing more about the biodiversity of our coastal and ocean environment.

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Volume 52, Part 2, pp. 327

OTHER RECENT SCIENCE BOOKS OF NOTE

(Editors Choice)

Voles, not Moles. A Personal Journey Connecting with Nature. Bondrup-Nielsen, Soren. 2021. Gaspereau Press Limited, Printers & Publishers, Kentville, NS. 233 pp. ISBN 978-1-554-47217-8.

A magical and absorbing autobiography of one of Nova Scotia's outstanding field biologists/ecologists.

Endless Novelties of Extraordinary Interest. The Voyage of H.M.S. Challenger and the birth of Modern Oceanography. MacDougal, Doug. 2019. Yale University Press, New Haven and London. 257 pp. ISBN 978-0-300-23205-9.

An engaging story of the Challenger expedition in the 1870s that established oceanography as a science. Note that the Maritime Museum of the Atlantic and others will be celebrating the 150th anniversary of its visit to Halifax in May 2023.

Scientist. E.O. Wilson: A Life in Nature. Rhodes, Richard. 2021. Doubleday, Penguin Random House LLC, New York. 268 pp. ISBN 978-0-385-54555-6.

An easy to read and engrossing biography of one of America's greatest biologists and naturalists, by a distinguished author. Every young scientist or aspiring scientist should read this book!

Proceedings of the Nova Scotian Institute of Science (2022)
Volume 52, Part 2, pp. 329-356

NSIS COUNCIL REPORTS

Reports from the Annual General Meeting
May 2, 2022 - 5:45 pm

AGENDA

161ST ANNUAL GENERAL MEETING
(This meeting will be virtual, via Zoom)

1. Minutes of the 160th AGM, 3 May 2021
2. Vote to accept Minutes of the 160th AGM
3. President's Annual Report (Tamara Franz-Odendaal)
4. Treasurer's Annual Report (Angelica Silva)
5. Editor's Annual Report (Peter Wells)
6. Librarian's Annual Report (Michelle Paon)
7. Membership Annual Report (Shea McInnis)
8. Webmanager's Annual Report (Romman Muntzar)
9. Publicity Annual Report (Brent Robicheau)
10. Student Science Communication Competition Annual Report (Cameron Ells)
11. Excursions Annual Report (Hank Bird)
12. Lecture Programme for 2022-2023 Report (Anne Dalziel)
13. Vote to accept the 10 Reports
14. Nomination of 2022-2023 Council (Tamara Franz-Odendaal)
15. Vote to approve the new Council
16. Any Other Business
17. Adjournment

Note: Following the AGM, at 7:30pm, there will be a Public Lecture via a separate Zoom Call. The Zoom link will be posted on the NSIS Website (www.nsis1862.ca) prior to the Lecture.

Dr. Gaynor Dr. Watson-Creed, Asst. Dean, Faculty of Medicine, Dalhousie University will present "Public Health Systems in Canada: Pandemics, Plagues, and the Power of Prevention".

Dr. Tamara Franz-Odendaal
NSIS President

MINUTES OF THE 160TH NSIS ANNUAL GENERAL MEETING

May 3, 2021

Meeting held virtually, via Zoom.com

Council Members & Observers Present: Tamara Franz-Odendaal (President), Tana Worcester (Past President), Hank Bird (Secretary, and Excursions), Angelica Silva (Treasurer), Peter Wells (Editor), Michelle Paon (Librarian), Patrick Upson (Webmaster), Anne Dalziel (Councillor), Tamara Franklin (Councillor), Tim Fedak (Observer, Nova Scotia Museum), Evans Monyoncho (Writing Competition), Romman Muntzar (Student Representative)

Members Present: Genice Halett-Tagley, Bertrum MacDonald, Carol Morrison

Regrets & Absent (Council Members & Observers): Nicole LeBlanc (Publicity Officer), Shea McInnis (Membership Officer), Sherry Niven (Councillor), Stephanie MacQuarrie (Councillor), Sally Marchand (Observer, Schools), Jillian Phillips (Observer, Discovery Centre), Yashar Monfared (Writing Competition), David Richardson (Associate Editor)

1. **Approval of the Minutes of the 159th Annual General Meeting of 14 September 2020:**
   There were no revisions to these Minutes.

2. **Motion to accept the minutes of the 159th AGM:**
   Moved: M. Paon
   Seconded: P. Wells
   All in favour: Approved via online poll.

3. **President's Annual Report (Tamara Franz-Odendaal):**
   The president thanked the 2020-2021 Council for its work and accomplishments during the past year, and she gave special thanks to those Councilors who are leaving at the end of the term and she welcomed new members who joined the council this year.

   The President also thanked David Richardson, Gail LeBlanc, The Editorial Board, and Carol Richardson for their work on producing and distributing the *Proceedings of the NSIS*.

She thanked Nicole LeBlanc for her many years and contributions as our Publicity Officer, and Patrick Upson who migrated our website to accept membership payments via PayPal.

It was a very successful year, even though Covid-19 compelled us to move many activities online. Our public lectures will continue to be, and they are being live-streamed and recorded and are available on YouTube. In perhaps 2 years' time we may move some of the lectures to a hybrid format (half in-person, half online). Council Meetings will also continue online indefinitely.

The President noted the very successful Public Lecture Series this year. She also thanked all the lecturers for sharing their knowledge, experience, and time on such diverse and wide-ranging topics. These were the lectures during 2020-2021:

Sept, 14, 2020: Dr Anne Dalziel (Saint Mary's University) – Diversity of the minnow trap.

Oct, 5, 2020: Dr Erin Bertrand (Dalhousie University) – Phytoplankton need their vitamins too: how the foundation of ocean food webs depends on micronutrients.

Nov, 2, 2020: Dr Glenys Gibson (Acadia University) – The life and times of marine invertebrates of the Minas Basin – a tale of polychaetes, plasticity, and microplastics

Dec, 7, 2020: Amy Tizzard (Nova Scotia Geological Society) – Evolution of the Oxford sinkhole.

Jan 4, 2021: Dr Michael Parsons (Geological Survey of Canada) – Metal mining in Nova Scotia: learning from the past to improve future environmental performance.

Feb, 1, 2021: Dr Derek Fisher (Mount Saint Vincent University) – Seeing through the smoke: cannabis and the brain.

March 1, 2021: Dr Gordon McOuat (King's College, Dalhousie University) – Brewing civilization: the science and culture of beer.

April 12, 2021: Dr Russel Wyeth (St. Francis Xavier University) – Wayfinding under the waves.

May 3, 2021: Dr Sarah Wells (Dalhousie University) – What we can learn from the strength of a mother's heart.

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

4. Treasurer's Annual Report (Angelica Silva):

As of 31 March 2021, the net worth of the NSIS was $36,039.65, held in our BMO bank account. This includes investments at CIBC-Wood Gundy which matured and the proceeds of which ($21,259.35) were transferred to our BMO account in March 2021.

Revenue from all sources were $6246.72 (mostly memberships); over 70% of individual memberships were paid via PayPal. Other revenue included $360 in Institutional Memberships, $422.09 in Income/Access Copyright Royalities, and a $1,500.00 WISE Atlantic contribution.

Expenditures amounted to $8439.50, $6,841.88 of which was for production of the Proc.N.S.I.Sand expenditures of $7,052.12 (mostly for *Proc.NSIS*, Science Fairs and the Writing Competition). The remaining expenditures included $70.00 for our website, $47.62 for NSIS Brochures, and $1,500.00 for Student Science Writing Competition prizes. (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 2021 due to Covid.)

The Treasurer noted that the NSIS has 130 members. (See the Membership Annual Report below.)

The Treasurer recommended that we engage Dr. Robert Cook to conduct an audit of our 2019-20 and 2020-2022 Financial Reports.

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

The Editor reported that Vol. 51 No. 1 of the *Proceedings of the NSIS* has been published in hard copy in February and distributed to NSIS members. It is also available digitally to members, and will be available digitally to non-members after August.

The Editor thanked the Editorial Board and especially David Richardson (Associate Editor), Gail LeBlanc (Production and Layout Editor), and Carol Richardson (Cataloguing and Distribution) for their work.

Volume 51, No. 2 of the *Proceedings* is in progress, with numerous commentaries, research articles, and a student paper lined up. Other items and contributions are being pursued,

The Editor encouraged current members of the NSIS and Council to write articles, including Commentaries. He also encouraged Council members to help seek articles for the PNSIS, including articles from past and present speakers, and from winners of the Student Science Writing Competition. He also requested suggestions for Editorials.

6. Librarian's Annual Report (Michelle Paon):

The Librarian reported that in 2020-2021, due to Covid-19, the Killam Library at Dalhousie was closed. This curtailed or delayed a number of activities, including collecting mail addressed to the NSIS.

There were no sales of the *Proc.NSIS* in 2020-2021. Copies of the most recent issue have been sent to Library & Archives Canada, the Library of Congress, and several indexing services.

A search was made through a number of indexing services for citations to *Proc.NSIS* articles, and the most cited ones were tabulated with information such as date of publication, number of citations, and date of most recent citation. Many have been cited scores of times. Some which were published decades ago are still being cited. The data indicate that the *Proc.NSIS* continues to have long-lasting research impact.

Other results of note during the year:

- Between August 2017 and March 2021 a total of 1283 complimentary copies of the Proceedings (from the overstock inventory) were distributed.
- The required forms to Access Copyright for the repertoire payment to publishers were submitted and NSIS received a payment of $422.09.
- 11 institutional partners renewed their subscriptions, currently there are 14 institutional members and 84 NSIS exchange partners.

7. Membership Annual Report (Shea MacInnis):

Mr. McInnis was unable to attend, but a summary of his submitted report is as follows.

By May 2021 we had 130 total members (up 29 since the last AGM). This includes:

- 2 Honorary members (no change)
- 21 lifetime members (up 8)

- 76 regular members (up 7)
- 16 student members (up 13)
- 8 free members from presenters of Lectures (no change)
- 7 free student members from the writing competition (up 1 from last year)

In addition, there are 14 institutional members.
We continued our policy of offering free 1-term memberships to both speakers and the students who submit for the writing competition.

Shea noted that almost three-quarters of paid memberships were via PayPal. He also noted that we have begun to attract gift memberships, especially for students.

8. Webmaster's Annual Report (Patrick Upson):

As noted elsewhere, one of big achievements was implementation and continued enhancement of an NSIS account on the PayPal electronic payment system, which now allows members to pay their dues online. The Executive Page was updated, and all 2020-2021 Lectures were added to the website.

The NS Hall of Fame index has been re-organized to use the person's last name then first name. Information about the Hall of Fame, including criteria and the nominating process (with submission form) has been added to the HoF main page. Also, a section was added to highlight our two current Honourary Members (Drs. Arthur McDonald and Mary Anne White).

Features were added to allow correspondents to directly route email to the President, the Secretary, or the Membership Officer.

Traffic on the website has been consistent with previous years.

Work continues with Chebucto (our service provider) to resolve a "303 Error" which occurs when too many links on the website are clicked in short succession.

9. Publicity Annual Report (Nicole LeBlanc):

Ms. LeBlanc was unable to attend, so when it is received a summary of her report will be added here.

10. Student Science Writing Competition Annual Report (Evans Monyoncho):

Yashar Monfared and Evans Monyoncho were thanked for taking over this year as Co-cordinators and running a very successful competition. Participation was from all 6 NS Universities and was high: 47 students registered to participate. A total of 32 papers were submitted (Acadia University initial submissions = 19, others = 13). Number of papers in the final round of the competition = 16 (9 undergrad, 7 postgrad).

A panel of 7 Judges reviewed the papers and the results were as follows:

- Undergrad Winner: Olivia Mellville (Dal)
  about Critical N-to-P Ratio in Wastewater
- Undergrad Hon. Mention: Kat Kabanova (Dal)
  about Littoral Macrofaunal Biodiversity
- Postgrad Winner: Morgan Mitchell (SMU)
  about Surface Ozone Trends in NS.
- Postgrad Hon. Mention: Thomas Robert Davies (Dal)
  about Genomics and Farming.
- Postgrad Hon. Mention: Megan Fass (St.FX)
  about Seaweed Harvesting in NS.

11. Excursions Annual Report (Hank Bird):

H. Bird reported that between late 2017 and the end of 2019, we conducted thirteen (13) science-based excursions for members and guests.

However due to Covid-19, NSIS Excursions have been on hold since the Spring of 2020, and will be so until further notice.

When coronavirus restrictions are sufficiently relaxed, we have the following possibilities in mind:

- Petroglyphs and Guided Nature Hike (Kejimkujik N.P.)
- Waterfalls of Nova Scotia (various sites)
- Cape Split Nature Hike (Scots Bay)
- NS Museum of Industry (New Glasgow)
- Shubenacadie Wildlife Park (Shubenacadie)

Also, when possible, we may be able to have a joint excursion with the Halifax Field Naturalists organization, guided by a HFN expert. Also, there is the possibility of a joint excursion in May 2022 with the Canadian Geological Association.

We welcome additional suggestions and possibilities.

12. Lecture Program for 2021-2022 – Report of the Organizing Committee (Anne Dalziel):

Ms. Dalziel said that the program is nearly complete, with just a few final details to be resolved.

13. Motion to accept the Annual Reports:

Moved: A. Dalziel
Seconded: P. Wells
All in favour: Approved via online poll

14. Report of the Nominating Committee for the 2021-2022 Council (Tana Worcester):

Tamara Franz-Odendaal thanked the outgoing Council and remarked that the Tana Worcester 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 2021-22:

President	Tamara Franz-Odendaal
Vice-President	Stephanie MacQuarrie
Past-President	Tana Worcester
Secretary	Hank Bird
Treasurer	Angelica Silva
Publicity Officer	Molly Murray (and Nicole LeBlanc)
Membership Officer	Shea McInnis
Librarian	Michelle Paon
Editor	Peter Wells
Webmaster	Patrick Upson
Councillor	Anne Dalziel
Councillor	Glenys Gibson
Councillor	Geniece Halttett-Tapley
Councillor	Youyu Lu
Councillor	Jinshan Xu
Councillor	Anne Dalziel
Student Representative	Romman Muntzar

There was a call for additional nominations from the floor. None were forthcoming.

15. Motion to approve the Nominations:
Moved: A. Dalziel
Seconded: A. Silva
All in favour: An online poll showed all voting councillors present were in favour of this slate of candidates.

16. Any Other Business:
2022 is the 160th Anniversary of the NSIS. We have begun to review the events that took place during the 150th Anniversary, and will begin planning in earnest for 2022 in the Fall.

17. Adjournment:
Motion by H. Bird to adjourn the 160th Annual General Meeting of the NSIS.

Respectfully submitted
Hank Bird
Secretary

PRESIDENT'S REPORT 2021-2022

This year NSIS celebrates their 160th anniversary. We initiated a social media campaign to highlight discoveries made by Nova Scotians over the years - I would like to thank all council members who helped make this happen. I hope our members have enjoyed these tidbits of news.

We had a great year, thanks to a very active and engaged Council. I would like to, in particular, thank Dr Anne Dalziel for organizing a stellar lecture series. New this year, we had some hybrid sessions and some sessions with multiple speakers. A highlight in the series for me was the student presenters on their research relating to the pandemic. I would also like to thank Peter Wells and the entire Editorial Board and support staff, for their work in producing excellent issues of the Proceedings.

Our big project this year was to revamp our website. This project is almost complete, and we are excited that our new website will be up and running soon. An enormous thank you to Abe Omorogbe and our website subcommittee for working on this project all year long. Members will see the new website launch this summer.

Another change for us was a modification to our Science Writing competition. This was changed into a Science Communication competition involving a writing and a video component, and enables student participants to make submissions in multiple formats. Thank you to Cameron Els for leading this endeavour.

We were joined mid-year by Brent Robicheau who stepped in as our publicity officer and is doing a fine job of promoting our lecture talks, and also promoting the Nova Scotian discoveries mentioned earlier. Romman Muntzar took over as our website manager mid-way through the year and Shea McInnis continues as our Membership officer. Thank you to all three for being actively involved in our council. It is fantastic to have some younger voices in our discussions and your input is highly valued. Our regular council members, Angelica Silva, who keeps track of our finances, and Michelle Paon, our librarian, thank you for all your many years of service. Hank Bird deserves a particularly special thank you for organizing every meeting and keeping our active business items front and center in our meetings.

I submitted a grant to the Halifax Regional Municipality to support a membership drive, which you will hear more about in September, if successful. We also added one more Nova Scotian researcher to our Hall of Fame, namely Dr. Ron O'Dor.

The following Public Lectures took place over the 2021-2022 year:

October 4th, 2021: Money Often Costs Too Much. Andy Kekacs, NS Woodlot Owners and Operators Association

November 1st, 2021: Making the transition to low-carbon energy in Atlantic Canada: How will we get there? Dr Wayne Groszko, NS Community College

December 6th, 2021: Covid-19 Student Research in NS. Kaleigh McLeod (SMU), Sumalya Amin (StFX), Hillary Fry (MSVU), Mark MacLean (Dalhousie Univ)

January 3rd 2022: Traditional Ecological Knowledge and Molecular Biology Side by Side. Rod Beresford (CBU), Lindsay Marshall (Potlotek First Nation, CBU), Anita Basque (Potlotek First Nation)

February 7th, 2022: Tidal Wetland Restoration and Ecosystem Services in the Bay of Fundy Dykelands. Dr Jeremy Lundholm (SMU), Dr Alana Pinder (CBU), Dr Danika Van Proosdij (SMU), Dr Kate Sherren (Dalhousie Univ)

March 7th, 2022: Tiny Materials for Big Challenges. Dr Mita Dasog (Dalhousie Univ)

April 4th 2022: Tick Talk. Dr Nicoletta Faraone (Acadia Univ)

May 2nd, 2022: Public Health Systems in Canada. Dr Gaynor Watson-Creed.

Respectfully submitted
Dr. Tamara Franz-Odendaal
NSIS President

TREASURER'S REPORT 2020-2021

April 1, 2021 - March 31, 2022

ASSETS 2021-2022 as of March 31, 2022	
Total Assets at BMO March 31, 2020	**$34,699.60**
REVENUE 2021-2022 as of March 31, 2022	
NSIS Membership (via paypal – Regular, LIFE, and Students)	2,981.90
NSIS Membership regular (cheque)	600.00
NSIS Membership Life (cheque)	300.00
NSIS Students (cheque)	30.00
NSIS Membership Institutions (cheque)	330.00
Income/ACCESS Copyright Royalties (cheque)	336.93
TOTAL REVENUE	**$4,578.83**
EXPENSES 2021-2022 as of March 31, 2022	
NSIS Proceedings PNSIS /Printing	1,659.45
NSIS Proceedings PNSIS/Layout	1,472.00
NSIS Brochures	150.00
Publicity, advertisement	106.95
PNSIS Mail out	496.50
NSIS 2019 Writing Science Competition	1,250.00
NSIS website re-design and development	772.92
BMO charges	11.06
TOTAL EXPENSES	**$5,918.88**

NSIS FINANCES 2021-2022

This is a year-end financial status report for the **Nova Scotian Institute of Science (NSIS) 2021-2022 period. The NSIS net worth is $ 34,699.60** currently at BMO **as of March 31, 2022.**

All NSIS 2021-2022 income and expenses are summarized for the **April 1st, 2021 to March 31, 2022, period**. **NSIS income during this period was $ 4,578.83** that arose from membership income from received cheques for **a total of $ 1,260** and from membership payments made via NSIS website **for a total of $ 2,981.90. Additional income was received from ACCESS Copyright Royalties for $336.93.**

NSIS total Expenses during 2021-2022 was $5,918.88 that resulted from costs associated to Printing of Proceedings of Nova Scotia Institute of Science (PNSIS) for $1,659.45; PNSIS layout costs of $ 1,472.00; NSIS brochures for $150; Advertising NSIS lectures of $ 106.95; Regular PNSIS mailing out costs to members for $ 496.50; NSIS Student Writing Competition for $1,250; NSIS website re-design and development for $ 772.92, and BMO charges for $11.06.

NSIS MEMBERSHIP 2021-2022

NSIS had a total of 133 active members that includes 74 regular members, 25 LIFE Memberships, 15 students, 6 Scientists NSIS lecturers, 2 Honorary memberships and 11 Institution members as reported by Shea McInnis, Membership officer.

Since 2020-2021 with help from **Patrick Upson and during 2021-2022** with help from graduate student **Romman Muntzar (MSVU),** NSIS has now the benefit of accepting **NSIS renewals and new membership**s to be paid via a paypal transaction directly from the current NSIS website link to **nsis.chebucto.org**. NSIS membership renewal and new memberships also continue to be received via regular mail as shown on website to be paid by personal cheque to NSIS physical address.

We thank **Carol Richardson** from Dalhousie University for her continuing volunteering with NSIS compiling mail and distribution. Many thanks to graduate student **Shea McInnis (SMU)** for his contribution as a Membership officer that compile and update NSIS membership by categories and to **Romman Muntzar** for her patience compiling and monthly transference of website payments. Special thanks also to **Tana Worcester** that helped a great deal with mailing payments and to all of you for renewing and inviting new members.

The **Nova Scotian Institute of Science is a not-for-profit and Charitable membership organization** that continues to dedicate all its resources towards communication and support of scientific issues relevant to all Nova Scotians by maintaining an **Annual NSIS Lecture series** (October to May) and it is now more accessible as it has become mostly virtual. **NSIS** continues to support science lectures, conferences, student science writing competitions, printing and producing the **Proceedings of the Nova Scotian Institute of Science (PNSIS)** to be distributed to all members. **Regional Science Fairs in the Province of Nova Scotia** did not occur due to COVID-19, therefore no financial support was provided.

This annual report is included yearly with the NSIS report submission to CRA Charities and it is also included on the PNSIS yearly issue.

Respectfully submitted
Angelica Silva
NSIS Treasurer
May 3, 2021

DRAFT Summaries for 159th NSIS Council Mee	**April 01/Mar 31**
Regular memberships	600
Paypal Memberships Regular + LIFE + stud	2981.9
Life memberships (cheques)	300
Paypal Memberhips LIFE	0
Student memberships (corrected from $20)	30
Paypal Memberships students	0
Institutional memberships	330
Sales ofProceedings-flora ns/birds	0
Sales Flora	0
ACCESS Copyright royalties	336.93
Provincial grant ns	0
Page charges/postage	0
AGM - dinner registrations	0
Donations	0
Field trips	0
Contributions from others -WISE Atlantic	0
	0
TOTAL INCOME/April 1st to March 31, 2022	**4578.83**
BMO as of March 31, 2022 (with paypal)	34,699.60
Deposits April 2021 to March 31- 2022 (N21)	**4,578.83**
Expenses April to March 31 (N53)	5,918.88

NSIS 2021- 2022 UPDATE EXPENSES - DRAFT	**Ap1/Mar31,**	**Pending**
PNSIS - printing PNSIS (PRINT 101)	1,659.45	
PNSIS - Layout (G. LeBlanc)	1,472.00	
Brochures annual/bookmarks/posters	150	
Publishing, advertisement	106.95	
PNSIS- mailout (SMU mail, DAL mail)	496.5	**242.43**
Flora of NS - reprint 100 copies		
Field trips guiding /entrance fees		
AGM lecture venue (Dalhousie Univ)		
Lecture sponsorships/student posters		
Sable Island round table funding		
Writing competition prizes	1,250	
Regional Sience Fairs contribution		
Student conference/ event funding		
Website annual fee		
Website domain name		
Website honorarium/design/revamp	772.92	**1,803.48**
Rental (monthly lectures/	0	
Office supplies -envelops/supplies/	0	
Registry of Joint Stock registration	0	
Charges BMO/ paypal	**11.06**	
TOTAL EXPENSES/ April 1st to March 31, 20	**5,918.88**	2,045.91

EDITOR'S REPORT
2021-2022

It has been another busy year for the Editorial Board of the PNSIS, as papers and other contributions continue to be submitted for consideration for publication. Thanks are due to all Board and Council Members for making the journal a successful voice piece for the NSIS and an outlet for natural and physical sciences of regional interest. We also thank the long serving Gail LeBlanc, our production and layout Editor, for her excellent service to the NSIS, and Carol Richardson for her work in distributing the PNSIS to NSIS members and other interested parties.

PNSIS Vol. 51, Part 2, 2021, with eleven contributions, was completed in September, 2021, and circulated to members in October 2021. Its highlight was the extensive paper on the seabirds of East Machias Island, in the outer Bay of Fundy, by Dr. Antony (Tony) Diamond of UNB, Fredericton.

PNSIS Vol. 52, Part 1, 2022 was completed in April 2022. It is a special Issue, *The Birds of Brier Island* (2^{nd} Edition), by the NSIS member and noted birder, Dr. Eric Mills, together with his distinguished naturalist colleague and avid birder, Mr. Lance Laviolette. This special Issue is already available on the NSIS website, open access. Some consideration is being given to have a limited printing if monies permit. It was published to coincide with the May AGM.

PNSIS Vol. 52, Part 2, 2022, a regular Issue, is well underway and should be published by mid- summer 2022. It will have the full range of contributions including an Editorial, Commentaries, Research Articles, Book Reviews, and Reports of the May 2022 AGM. No doubt there will also be an item celebrating the notable 160^{th} Anniversary of the NSIS. We are also adding a new section – a summary of the current years' talks, in this case '21-'22.

As usual, the Editors welcome contributions to the Proceedings from all NSIS members and especially from those giving annual lectures to the NSIS. Submissions from other interested and active scientists and citizen scientists in Nova Scotia or other parts of the Maritime Provinces are also welcomed. The Proceedings and the website of the NSIS provide the voice piece for the Institute along with the annual lectures. They reflect the very active and varied science that is conducted in our ocean province and region.

Submitted by
Peter G Wells
Dalhousie University, Editor

David H.S. Richardson
Saint Mary's University, Associate Editor

April 8th, 2022 (revised May 3rd, 2022)

LIBRARIAN'S REPORT
2021-2022

(submitted for the May 2022 AGM)

The NSIS Librarian serves as a liaison between the Dalhousie University Libraries and the Nova Scotian Institute of Science. The Librarian communicates with NSIS journal exchange partners from around the world and oversees the receipt of partner journals. She also works 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 2021/2022, there were no sales of the *Proceedings* from the Killam Library's Reference & Research Services Office.

Access Copyright

During the summer of 2021, the NSIS Librarian submitted the required forms to Access Copyright for the repertoire payment to publishers. NSIS subsequently received a payment of $336.93.

Institutional Members and Exchange Partners

NSIS has 15 institutional members, including the Bibliothèque Centrale du Muséum National d'Histoire Naturelle in Paris. This institution ended its exchange program in the fall of 2020, but it continues to support NSIS via a new institutional membership. NSIS also has 84 journal exchange partners.

NSIS Exchange Journal Collection

On behalf of NSIS, I would like to thank Carol Richardson and the Dalhousie Libraries' Resources staff, who process the exchange journals and make them shelf-ready. NSIS receives journal issues from exchange partners around the world. From mid-March 2021 to mid-March 2022, NSIS received 50 issues (an increase from the 36 issues received during the same period in 2020-21).

Over the past few years, as print publication costs and postage rates have increased, the number of scholarly scientific societies participating in the print journal exchange program has decreased.

This year was no exception. In October 2021, NSIS received news from the Natural History Museum (NHM) in London, UK, that in 2022, the exchange journal *Systematics & Biodiversity* would no longer be available as a print exchange journal and would transition to an online subscription instead. Subsequently in March 2022, the Zoologisch-Botanische Gesellschaft in Österreich (Zoological-Botanical Society in Austria) notified NSIS that for financial reasons, they would no longer participate in the print exchange program. The society transitioned its journal *Acta ZooBot Austria* to an open access online publication available at: https://www.zobodat.at/publikation_series.php?id=146

Report respectfully submitted by
Michelle Paon, NSIS Librarian
April 19, 2022

WEBMASTER'S REPORT 2021-2022

This year, the main tasks that were done were updating the NSIS website with the upcoming talks on the Public lectures page every month prior to the day of the talk and updating the archive lectures pages on the website as well. 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. In December, I took over the Webmaster duties from Patrick Upson and he officially handed over the passwords and account details for the Chebucto, Wordpress, Google and PayPal accounts.

Additionally, the NSIS Science Writing Competition webpage was updated, Poster Competition information was added and Dr. Ron O'Dor was added to the Hall of Fame on the NSIS website.

Lastly, a new and refurbished website is being designed by Abraham Omorogbe and I have been keeping up with his updates on the process as well.

Submitted by
Patrick Upson
Webmaster

STUDENT SCIENCE WRITING COMPETITION 2022

In 2021, I was one of the competition judges. I later volunteered as the competition coordinator and benefitted from the generous time and archive of digital files from long-time former coordinator Hank Bird.

On my initiative and responsibility there were some changes for the 2022 competition.

1. In addition to evaluating submissions from separate undergraduate and graduate groups of students, a third group of submissions were invited from Nova Scotia Community College students from across Nova Scotia.
2. In addition to funds typically provided by the NSIS as prizes, there would be a fundraising effort to increase the pool of prize money available. For three groups of submissions, each having the same $750 prize, a total of $2250 was desired.
3. In addition to the typical 3500-word essay used as a submission in previous years, this year there were additional submission requirements for a 400-word article on the same topic (as if it were for a local community paper article read by people who are not science or technical specialists), and a 4-minute video (as a "You Tube" type of video clip).
4. The name of the competition was changed to Student Science Communications Competition since it is now more than a writing competition.
5. In addition to individual submissions, group submissions would be accepted on an equal basis, but with a designated "representative" for the group with the competition.
6. In a year with COVID, and recently developed digital communication skills, the submission time was extended, with an announcement of winners to be in May (after the university year was over, since there would not be an in-person event for making awards, as had been done in earlier years).

Not everything turned out as was hoped. COVID, automatic email spam filters, and some university work stoppage activities were also influences on the competition. Some of the results of these initiatives, changes, and efforts included:

- A relatively small number of submissions.
- A mix of individual and group submissions.
- No submissions by Nova Scotia Community College students
- A generally unsuccessful response to the emailed fundraising appeals for academic faculty members, the private sector, and organized labour. ($500 was pledged and expected to be received by the NSIS in May 2022).
- For 2 x $750 prizes, when counting the pledged $500, the net contribution by the NSIS is $1000, which is less than last year.
- While April was expected to be an available time for competition judging, that did not turn out to be the case. It will be completed later in May 2022.
- The mix of an essay plus 400-word article plus 4-minute video seemed to work well to the eye of the competition coordinator, but the real debrief by judges and interested NSIS Executive, will happen after the awards are made.
- The competition was promoted through the typical NSIS social media channels.
- A new email address was used for the competition: NS.Science.1862@Gmail.com.
- While emailed communications to raise the competition profile, to seek prize money donations, and to seek a broader group of submissions were not on their own successful, a debrief may result in recommendations for 2023 that include working to not have NSIS emails treated as spam, and to make greater use of the telephone.

So, several new things were tried in 2022, with mixed success. Still there are and will be some useful lessons learned. I hope to prepare a 2023 competition report for the 2023 version of this meeting, with a significant improvement in the number of submissions, in the prize money donations, and in the profile for the NSIS.

Cameron Ells, Coordinator
NSIS 2022 Student Science
Communications Competition

PUBLICITY OFFICER REPORT 2021–2022

Highlights for the AGM:

New Publicity Officer (Brent Robicheau; Dalhousie Biology PhD Student) joined NSIS executive team in December 2021. Many thanks to S MacQuarrie for taking on the role of interim Publicity Officer prior to this position being filled.a

Publicity Officer has been working to increase our Twitter followers. In general, we continue to advertise the monthly lecture series (as well as other NSIS events, for example the student science communications competition) through Facebook and Twitter posts.

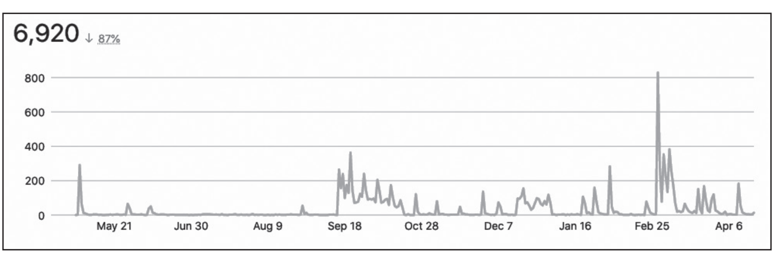
The publicity officer led a focus group of graduate students at the Dalhousie Biology Dept. with the goal of generating some new ideas for increasing student membership within the NSIS. This focus group resulted in a preliminary list of ideas that are currently being refined and discussed by members of the NSIS executive team.

The Publicity Officer and Vice-President have been collaborating to generate a series of social media posts on "NS Inventions and Inventors" in celebration of the 160-year anniversary of the NSIS. Several of these have now been posted to social media with more to come as the year progresses.

The Publicity Officer is organizing the book prizes for our forthcoming "160-year membership drive".

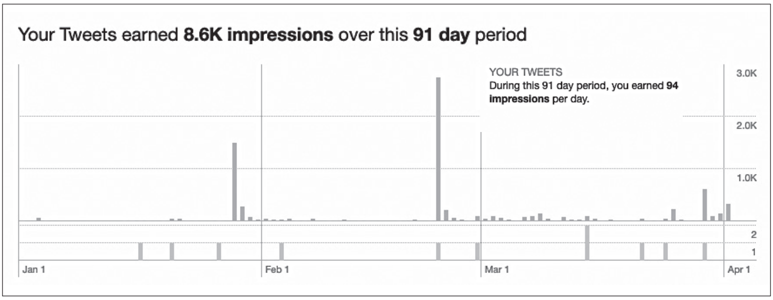
Facebook (past year; 1-May-2021 to 1-May-2022)

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."



Twitter

(Twitter limits to 3-month window for data analysis)



NSIS EXCURSIONS 2022

Due to Covid-19, NSIS Excursions have been on hold since the Spring of 2020, until the present. Now that the covid restriction have eased somewhat, we are planning for some in 2022.

At the time of writing, we are working with the Halifax Field Naturalists organization for them to provide a guided nature walk in the Purcell's Cove Backlands in late May. We are also working with the staff at Kejimkujik National Park for them to provide us with a guided outing in July involving the petroglyphs and a nature walk.

We have also been considering one or more of the following:

Waterfalls of Nova Scotia	(various sites)
Cape Split Nature Hike	(Scots Bay)
NS Museum of Industry	(New Glasgow)
Shubenacadie Wildlife Park	(Shubenacadie)

We welcome additional suggestions and possibilities.

—

For the record, we did thirteen excursions in late 2016, in 2017, in 2018 and 2019:

- Natural History of McNab's Island
- Annapolis Royal Historic Gardens
- The Science and Art of Making Beer
- 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").

Hank Bird
Excursions Coordinator

PUBLIC ONLINE LECTURES 2022-2023

October 3, 2022
How the black soldier fly can help turn the global protein crisis around
Dr. Greg Wanger, Oberland Agriscience

November 7, 2022
Drawing on Science: Mastodons of Nova Scotia
Dr. Tim Fedak, Nova Scotia Museum

December 5, 2022
New lessons from old mountains; what are our rocks trying to tell us?
Dr. Deanne van Rooyen, Cape Breton University

January 9, 2023
Getting Nova Scotia Off Oil, Off Coal, and Off Gas
Dr. Kathlyne Nelson, Nova Scotia Department of Natural Resources and Renewables

February 6, 2023
Student symposium: Climate Science in NS

March 6, 2023
Accelerating natural ocean CO2 sequestration as a climate change solution? Testing the safety and viability of Ocean Alkalinity Enhancement
Dr. William Burt, Planetary Technologies

April 3, 2023
How to Stop Global Warming
Dr. Andrew MacDougall, St. Francis Xavier University

May 1, 2023 | AGM 2023
Winter: A Bugs-Eye View
Dr. Jantina Toxopeus, St. Francis Xavier University

ANNUAL MEMBERSHIP OFFICER REPORT 2022

Summary

This year we continued to encourage members to buy gift memberships for others this year. Additionally, changes were made as to who receives a complementary membership for participating in the SSCC; previously, all entrants received a complementary membership, but this year it was changed such that only winners and honourable mentions receive. As such, in this report all comparisons made between the 2022 and 2021 membership counts will not include participant members. Plans were made to recruit more members, and to increase student interest in the NSIS. To me, these plans seem like a great idea to further interest in the NSIS and I am feeling optimistic for the 2022-2023 year.

At the 2021 AGM, it was reported that there were 123 total members of the NSIS (not including the 7 competition participant members). At this AGM, there are currently 122 active members of the NSIS.

Membership Overview

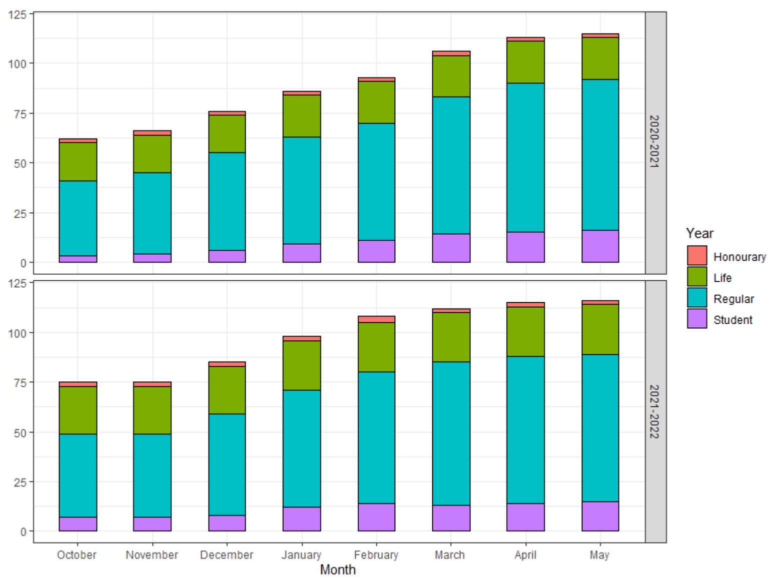
To date, there are currently 122 active members of the NSIS. This is effectively unchanged from 2021.

- 74 Regular - 61% of membership (compared to 76 in 2021, 62% of membership)
- 25 Life - 20% of membership (compared to 21 in 2021, 16% of membership)
- 15 Student - 12% of membership (compared to 16 in 2021, 13% of membership)
- 6 Lecturers - 5% of membership (compared to 8 in 2021, 7% of membership)
- 2 Honourary - 2% of membership (unchanged from 2021)

Membership Growth

The overall number of members did not significantly change between the 2021 AGM and the 2022 AGM. However, many more members became life members. While in 2021 only 16% of the membership was life members, now 20% of the membership are life members. This is not an insignificant change, and it is reassuring to see so many people expressing their interest in the longevity of the NSIS. Below is a graph comparing the monthly counts of Regular, Student, Life, and Honourary members during the 2020-2021, and 2021-2022 years. Interestingly the 2020-2021 year showed continuous growth from October to May, and the 2021-2022 year showed rapid growth between November and February, and slow growth from February to May. Additionally, the membership counts in the 2021-2022 year were much higher from October-April when compared to the 2020-2021 year. April and May show essentially the same counts during both years.

Shea McInnis



NOMINATIONS FOR NSIS COUNCIL 2022-2023 SLATE

President	Stephanie McQuarrie
Vice-President	Anne Dalziel
Past President	Tamara Franz-Odendaal
Secretary	Hank Bird
Treasurer	Angelica Silva
Editor	Peter Wells
Librarian	Michelle Paon
Publicity Officer	Brent Robicheau
Web Manager	Romman Muntzar
Membership Officer	Shea McInnis
Councillors:	
Councillor	Geniece Hallett-Tapley
Councillor	Youyu Lu
Councillor	Jinshan Xu
Councillor	Nicoletta Faraone
Observers:	
Nova Scotia Museum	Tim Fedak
Discovery Centre	Nora Whelan
Writing Competition	Cameron Ells
Student Representative:	Ale Torres
Associate Editor:	David Richardson

NSIS 2022-2023 LECTURE SERIES NSIS1862.CA

October 3
How the black soldier fly can help turn the global protein crisis around

Dr. Greg Wanger
Oberland Agriscience

Insect farming is a growing industry whose goal is to help address the protein crisis.

Dr. Wanger will discuss the black soldier fly, which can bio convert our food waste into a high-protein insect meal.

November 7
Drawing on Science: Mastodons of Nova Scotia

Dr. Tim Fedak
Curator of Geology, Nova Scotia Museum

The new NS Museum exhibit Age of the Mastodons shares some of the exciting new research of **Mastodons** from Nova Scotia.

Dr. Fedak will summarize recent mastodon discoveries from both latest field discoveries, as well as from new research of mastodon fossils found almost two hundred years ago.

December 5
New lessons from old mountains; what are our rocks trying to tell us?

Dr. Deanne van Rooyen
Associate Professor, Acadia University

The Appalachian Mountains in Canada's Atlantic Provinces have a long history of study.

This talk will take you behind the scenes of geological research and illustrate how the **geology** of where we live influences every part of our history and informs decisions we make in the present.

January 9
Getting Nova Scotia Off Oil, Off Coal, and Off Gas

Dr. Kathlyne Nelson
NS Department of Natural Resources and Renewables

Nova Scotia has set ambitious climate change goals.

Dr. Nelson will share her work on **energy efficiency** and **renewable energy** in the province with a focus on helping the most vulnerable Nova Scotians.

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 2022-2023 LECTURE SERIES NSIS1862.CA

February 6
Student Symposium: Climate Science in NS

Join us as we discover the latest research findings of **student scientists** working at nearby NS research institutions, who are studying topics related to climate change in the province of Nova Scotia.

March 6
Accelerating natural ocean CO2 sequestration as a climate change solution? Testing the safety and viability of Ocean Alkalinity Enhancement

Dr. William Burt
Planetary Technologies

Dr. Burt's talk will outline a process called **Ocean Alkalinity Enhancement** (OAE) that has the potential to remove CO2 from the atmosphere while de-acidifying our oceans. The premise of OAE will be discussed, as well as the research being done into it's viability and safety, and the role Halifax is playing in this exciting new field.

April 3
How to Stop Global Warming

Dr. Andrew MacDougall
Associate Professor, St. Francis Xavier University

For the past 15-yrs **climate science** has focused on how long carbon sinks can continue to absorb carbon before they become saturated and potentially transition to carbon sources.

This talk will focus on the findings of this research including climate-carbon feedbacks loops, the extraordinarily long lifetime of global warming, and the need to reduce emission to zero to stabilize global temperature.

May 1
Winter: A Bug's-Eye View

Dr. Jantina Toxopeus
Assistant Professor, St. Francis Xavier University

Understanding how animals interact with and survive low temperatures is important, especially as our winters become less predictable due to climate change.

This talk will focus on the **over-wintering biology of insects**, and what these chilly critters can teach us about surviving in the frozen state!

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

NOVA SCOTIAN INSTITUTE OF SCIENCE

MEMBERSHIP FORM 2022-2023

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

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.

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