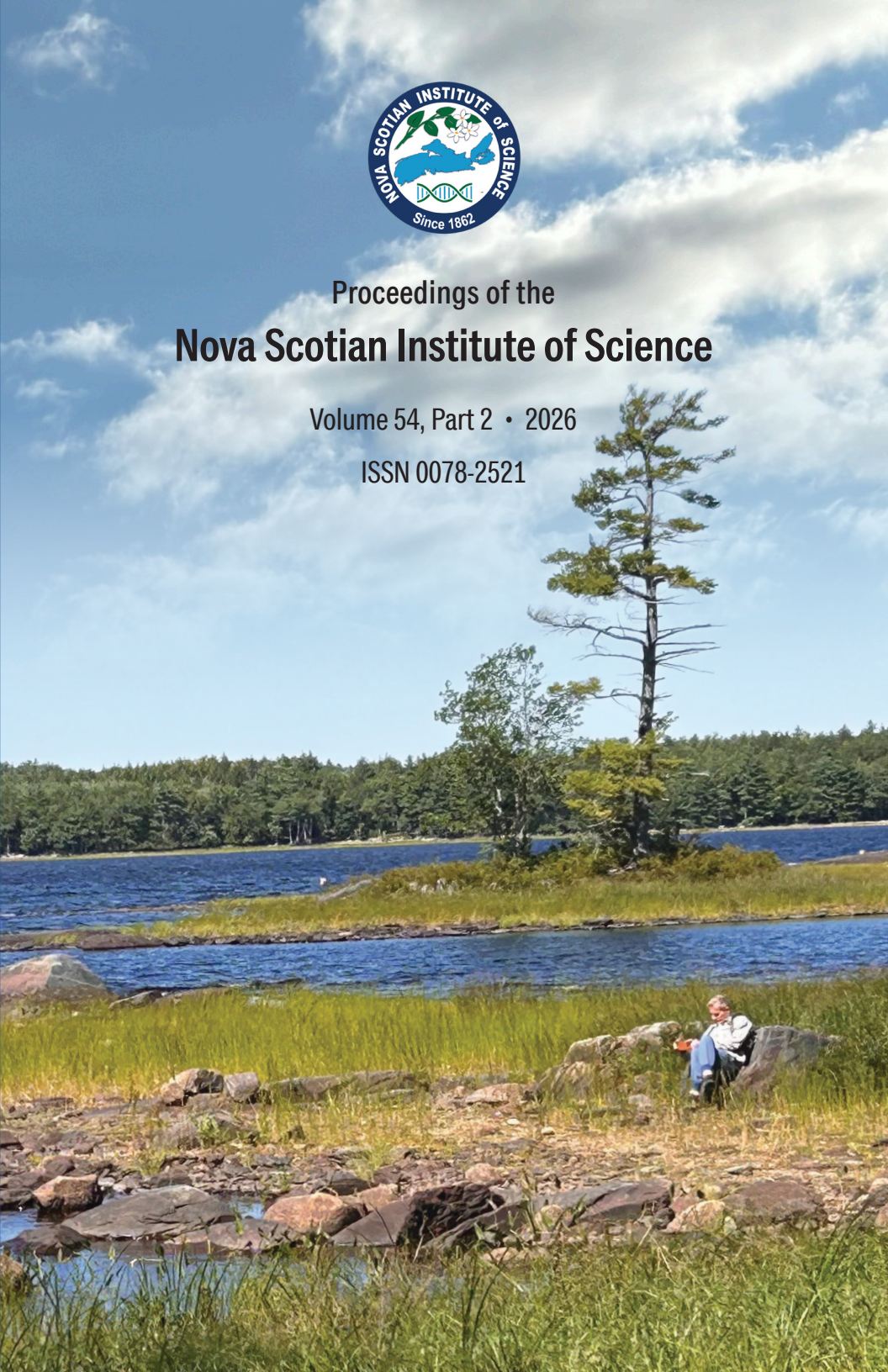


Proceedings of the

Nova Scotian Institute of Science

Volume 54, Part 2 • 2026

ISSN 0078-2521

The *Proceedings of the Nova Scotian Institute of Science* (PNSIS), published since 1863, is a peer-reviewed, general science journal containing editorials, commentaries, scientific articles, book reviews, and reports of the annual general meetings of the NSIS Council. It is published annually, with occasional special issues. Contributions represent the wide range of natural and physical science currently being conducted in the Province and region, as well as research in engineering and the health professions. Articles often originate from the annual series of public talks, sponsored by the NSIS. Together with its website, it is the voice-piece of the NSIS. Everyone active in science and citizen science in Nova Scotia and the Maritimes is encouraged to contribute articles, as well as to be members of the NSIS.

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This journal is abstracted in:

Biological Abstracts
BIOSIS Previews
GeoRef
Zoological Record
CAB Abstracts

Title: Proceedings of the Nova Scotian Institute of Science
ISSN Print: 0078-2521
ISSN Online: 2292-7743

Cover: View of Kejimkujik Lake, from Peter Point (Helga Guderley).

Back cover: Left: Humpback whale, *Megaptera novaeangliae*, NSIS banner, spiral galaxies (Hank Bird); a display of mushrooms on a tree stump in Sir Sanford Fleming park (P.G. Wells).

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EDITORIAL

HIGHLIGHTING NOVA SCOTIA'S "OCEAN PLAYGROUND" IN THIS ERA OF CLIMATE CHANGE – ANOTHER IMPORTANT ROLE FOR THE NSIS?

Nova Scotia is celebrated for being Canada's ocean province. Most citizens live near the coast, often in small communities, and they understand the need to protect our diverse ocean habitats. That said, new opportunities abound for improving the protection and conservation of our marine species, ecosystem health, and associated human health. As we respond to emerging problems, we should continue to be an example for other coastal jurisdictions, local to national to global, during this era of rapid climate change. Maintaining ocean health in the broadest sense is critical to our economy, tourism, food supply, and the environment. This core message should be repeated all levels of government and society, encouraged by activities of the NSIS and its members.

Nova Scotia is doing many things the right way to safeguard ocean ecosystems. Halifax and other locations in the province are recognized centres for ocean research, monitoring, technology, education, and training. Citizen groups are active with initiatives to promote ocean literacy. For example, during every June, the city of Halifax and many communities throughout the province celebrate Ocean Day and Ocean Week. This year, an exciting new initiative called Coastal Week was organized by the Ecology Action Centre and the Coastal Coalition of Nova Scotia. This involved groups such as CARP (Clean Annapolis River Project), CWF (Canadian Wildlife Federation), the Upper Bay of Fundy Research and Management Consortium, BoFEP (Bay of Fundy Ecosystem Partnership), CPAWS (Canadian Parks and Wilderness Society), and others. In addition, there is a long-standing annual beach litter cleanup program in hot spots such as McNabs Island in Halifax Harbour and elsewhere throughout the province. Other actions include the ongoing protection and rescue of the endangered North Atlantic right whales by the CWF (Sean Brillant, pers. comm.)

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and the coastal monitoring of contaminants in blue mussels and sediments (A. Scovil, pers.comm).

Nova Scotia has important ocean literacy programs. For example, the Ocean School at Dalhousie University has been in place for several years. There is also a new cooperative program on ocean literacy that involves the NS Department of Education and Early Childhood Development, the International Ocean Institute (IOI-Canada), and BoFEP. It provides assistance to high school teachers focusing on ocean topics and supporting science demonstrations. Recently, the Beaty Centre for Marine Biodiversity at the Ocean Frontier Institute of Dalhousie was opened; its aquaria and wonderful ocean displays are ocean literacy in action. The blue whale skeleton hanging above its displays is breathtaking to look at and brings home the wonder of the ocean and the importance of marine species protection!

However, many challenges and much work remain. Federal marine environmental quality (MEQ) or ocean health is a basic component of Canada's Ocean Act (1997) and programs related to this Act and others have thrived at Fisheries and Oceans Canada (DFO). Unfortunately, current activities are threatened by severe program cutbacks and the retirement or loss of irreplaceable dedicated ocean experts. This will affect regional work on MPAs (Marine Protected Areas), including related monitoring and support of local community programs. Despite the UN goal of 30% ocean protection by 2030, too few MPAs have been established, especially for the Bay of Fundy. Blue Beach, a renowned paleontological site on the Avon River estuary, is one site that needs formal protection (see the article in this PNSIS Issue).

Provincially, the NS Coastal Protection Act has been rejected by the current government, despite all party support. Hopefully, its passage is just delayed as there is much public support for coordinated coastal land management and protection. The current government is in favour of renewed gold mining on coastal lands despite the threat to water quality of rivers and estuaries. There has only been a limited study of possible recovery from such mining activity. After regional oil spills, e.g., Chedabucto Bay, Cape Breton Island, oil may persist along the shorelines. Ongoing concerns continue related to the impact of sea cage (open pen) salmon farming, of dams and causeways on our rivers and estuaries, and of future offshore energy wind farms. In these cases, monitoring and detailed environmental assessments are needed.

The list of ocean issues is obviously long! The NS provincial departments need to be more engaged. For example, it was disappointing to see poor attendance at a recent US-Canada GOMC (Gulf of Maine Council) meeting. This was despite the importance of the Gulf of Maine and Bay of Fundy in many areas to the provincial economy and the agreement since 1989 to collaborate on environmental quality issues that are cross border in nature. Given the many issues and opportunities that involve our coasts and offshore waters, the province must do better!

What can NSIS and its members across the province do to enhance the protection of our ocean spaces? The answer is much! For example, support Ocean Day and Ocean Week each year. We could also have a special series of ocean talks in the annual NSIS program. Other possible activities could be to invite provincial policy and management staff for a discussion or have a special "Ocean Health" issue of the PNSIS. This could cover both marine ecosystem and human health (see Wendy Watson-Wright's paper in PNSIS 52-2, 2022). The NSIS could also support more excursions to the coast for its members, as described in this Issue, and engage with other groups such as BoFEP and the Halifax Field Naturalists. Finally, NSIS should consider participating in the 12th Ocean Conference that is being planned for Halifax, May 2027.

Our Nova Scotia is an Ocean Province. We must do more to protect our portion of the blue planet. Let's open a discussion within NSIS on the way forward. In the meantime, enjoy the various papers in this Issue of PNSIS, some of which have a marine focus. For inspiration, take a walk along our beautiful coast or a swim at a local beach. We are after all an ocean playground!

Acknowledgements Thanks are due to David Richardson and Mike Butler for their helpful comments on the draft.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 399-415

WATER RESEARCH IN NOVA SCOTIA IN THE EARLY SEVENTIES – A PERSONAL PERSPECTIVE

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PREAMBLE

Late in the Fall of 1969, I resigned from my position as a senior research chemical engineer with a US oil company and drove my brand new, yellow Barracuda convertible (Fig 1) from Staten Island, New York up to Halifax, Nova Scotia, where I had decided to reside.

At that time, employment opportunities for a person with my academic background and industrial research experience were distinctly limited in Halifax. However, through the good offices of Dr. William Bridgeo, the Dean of Science of Saint Mary's University (SMU), I obtained a part-time appointment as a computerization advisor to the University President, Dr. Henry Labelle, S.J., in January, 1970.

My subsequent computerization experiences after being made an associate professor in the university's Chemistry Department in 1972, and promoted to full professor in 1980, have been reported elsewhere (Young 2025).

What follows here are recollections of my early water related research experiences while at SMU in 1970-73.



Fig 1 The Barracuda.

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WATER STUDY 1970

Introduction

In 1965, the Government of Nova Scotia decided to assume responsibility for treating the effluent from what was then the Scott (Maritimes) Pulp Limited mill. Its Boat Harbour effluent "treatment" facility represented a potential health hazard for a neighbouring indigenous First Nations community.

Shortly after my arrival at SMU in 1970, the Provincial Minister responsible for the Water Act offered me a contract to assess this situation and make recommendations for its amelioration.

Site Visitations and Recommendations

After carrying out a number of onsite surveys and water quality analyses, I reported back in December 1970 that the lignin and cooking liquor content of the effluent stream delivered into Boat Harbour was high by normal industry Kraft process delignification standards. I proposed a number of measures initially aimed at reducing this pollution problem by up to 50%.

Illustrated in Fig 2 is one of these measures. The installation of an array of aerators to reduce chemical oxygen demand was implemented.

This measure proved inadequate, given the increasing organic loading of the effluent stream. That led to the buildup of a layer of lignin rich solids at the bottom of Boat Harbour. The use of this ineffective effluent



Fig 2 The Boat Harbor effluent aeration system.

treatment system was abandoned when the mill was finally closed down in 2020. Unfortunately, the harbour remains contaminated and is unlikely to be cleaned up.

WATER STUDY 1971

Introduction

As part of my teaching responsibilities I regularly planned and delivered a section of the chemistry department's first year, inorganic chemistry course and its associated laboratory section.

This gave me regular opportunities to recruit promising first year students and provide them with employment and early research experience in my research program in the following summer, beginning in 1971. In that summer, chemistry students Paul MacGillivray, Richard Martin, Glen Roger, Vipin Segal and Ralph Wasson, biology student James Baker and geology Diane Gregory joined my research group. Aided by graduate chemistry assistant Vaughan Munroe, these students carried out several environmental water quality analysis studies.

A Water Supply Manganese Contamination Problem

With a grant from the Inland Waters Branch of Environment Canada, I was asked to investigate a problem of manganese contamination of the municipal water supply of the City of Dartmouth. The incoming lake water contained soluble colourless manganous ions that precipitated out as coloured manganic oxide solids when oxidized by chlorine in the municipal water treatment plant:

$$\underset{\textit{colorless}}{Mn2+(aq)} + 2H2O(l) + Cl2(aq) = \underset{\textit{brown}}{MnO2(s)} + 4H+(aq) + 2Cl\text{-}(aq)$$

Small quantities of this gelatinous brown insoluble compound deposited and gradually accumulated on internal surfaces of the water treatment plant and distribution pipelines. Periodically, these brown deposits detached into the water flow through the plant and found their way into the domestic water supply where they settled on garments in domestic washing machines, resulting in the mayor receiving telephone calls.

The Dartmouth City Water Supply System

In 1971, the Dartmouth city water supply originated in Lake Major from which it was pumped through a pipeline into an embayment



Fig 3 Water flow into the Lake Topsail embayment.

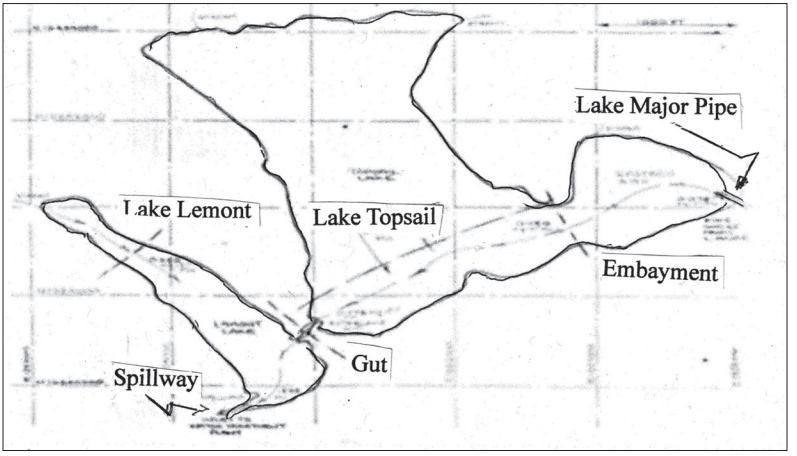


Fig 4 Water flow path through the lake system.

in the eastern shore of Lake Topsail, illustrated in Fig 3. From this point, the water supply flowed through Lake Topsail to the municipal water treatment plant on the western shore of Lake Lemont, shown on the map in Fig 4.

Site Inspection Tour

Our site inspection tour began at the water treatment plant on the western shore of Lake Lemont where the water over-flow at the plant spillway appeared to be clear of suspended solids and colourless.

Paddling eastward by inflatable canoes, we observed a light lignin coloration but no suspended solids in the water flow through the narrow gut that joined Lake Lemont to Lake Topsail. This suggested to us that the insoluble brown manganic compound found downstream on laundry was present in the streamflow through the lake system in the form of soluble, virtually colorless, manganous ions.

Continuing upstream, we reached the eastern end of Lake Topsail where the system water supply from Lake Major discharged from the pipeline into the Lake Topsail embayment illustrated in Figs 3 and 4. Actually, the pump was not turned on during our one month site visit.

In this embayment, we observed a submerged deposit of solids in the immediate vicinity of the outlet of the pipeline. Poking it with a stick, we found that this deposit was composed of a readily disturbed layer of fine solids more than a meter thick and on a firm base.

The location and nature of this deposit suggested that it was likely formed from solid particles transported in the water through the pipeline from Lake Major. The particles then settled out in the vicinity of its outlet in Lake Topsail which served as a solids settling pond. We were told that the water supply exiting from the pipeline was often observed to be laden with silt.

We surmised (i) that small solid particles containing a concentration of an insoluble manganic manganese compound were conveyed through the water delivery pipeline from Lake Major and deposited in the Lake Topsail embayment; (ii) that the insoluble manganic constituent of these particles was gradually reduced to soluble manganous ions by reaction with decomposing organic matter in the deposited silt layer; (iii) that these manganous ions migrated upwards in the interstitial water column in the silt layer and out into the overhead streamflow and through the lake system to the water treatment plant; (iv) that at the treatment plant, the ions were oxidized by chlorine gas forming insoluble manganic oxide molecules; (v) that a gradual buildup of theses solids occurred on the walls of the water supply distribution pipework system; and (vi) that after a certain amount of thickneking, this solids layer collapsed, sending a pulse of virtually pure gelatinous brown manganic chloride forward to stain the laundry.

This reaction pathway would explain how manganese embedded in solids in Lake Major became virtually pure insoluble manganic chloride, with likely a certain amount of ferric chloride occurring downstream of the treatment plant.

During our onsite visit of approximately one month, the Lake Major water delivery pump to the Lake Topsail embayment was never turned on.

In this period, upward diffusion of manganous ions through the interstitial water phase should have led to a greater decrease in their concentration at the top of the silt layer than at its bottom.

Manganous Ion Concentration Determination

After our initial visit to the Lake Topsail embayment, we returned to it with a hammer and a one meter length of a plastic pipe and two rubber bungs. We hammered the pipe down into the silt bank to obtain a vertical sample, removed the pipe and closed its ends with the rubber bungs.

Back in the lab, we cut the silt filled pipe into a set of short lengths and temporarily closed their ends with rubber bungs. Removing the rubber bungs, we spooned the silt contents of each pipe section in turn into a vacuum filtration system and separated its water and solids contents. We then carried out atomic absorption analyses for manganese concentrations in the water samples.

I have been unable to track down the lab book in which these analytical data were recorded. However, I do recall that there was approximately a tenfold decrease in the manganous ion concentration in the water phase, from the one meter depth in the silt layer up to its surface.

To check our assumption that the inflow from Lake Major contained significant amounts of manganic manganese in its suspended solid particle phase, we had hoped to take water samples at the pipeline outlet and filter and analyze the two phases for their manganese contents. Unfortunately, we were unable to visit the Lake Major site and the pump was never turned on during the time of our study of the Lake Topsail embayment.

Summarizing

In our final project report (now lost), we proposed a plausible reaction path that merited further investigation. Insoluble manganic manganese dispersed in a suspension of solid mineral particles delivered from Lake Major became a solution of manganous manganese in Lake Topsail and a suspension of virtually pure, insoluble manganic oxide occurred following chlorination in the treatment plant on the shores of Lake Lemont. We recommended further study of the silt deposit in Lake Topsail and an investigation of the practicality of extending

the inlet section of the Lake Major pumping station pipeline back to a location at which less silt would be picked up when the pump was turned on. Unfortunately, we had no opportunity to inspect this part of the treatment system.

My students had an enjoyable early summer employment experience transversing the lakes gathering and analyzing water samples. Swimming was not permitted in the water supply lakes.

Perhaps there is a rich manganese ore deposit somewhere in the watershed area of Lake Major, possibly detectable by an unnaturally high ratio of dissolved manganese to iron concentrations in the flow of an influent stream.

Footnote

The Lake Lemont water supply plant was decommissioned in the early 2000's. It was replaced by a new water supply plant installed on the shore of Lake Major adjacent to the pumping station that had previously served to deliver the water supply to Lake Topsail.

In the new water supply plant, chemical treatment of the raw water supply from Lake Major includes solidification of a small dissolved manganous ion content by oxidation with chlorine gas, followed by filtration of it and any suspended manganic manganese solids in the raw water supply. The raw water manganese content has been trending downward over the past ten years and averaged 31μ g^{-1} in 2024-25; the average treated water level was 2 μ g^{-1} in that year. (Edge 2025).

A River Water Quality Study

The second project that we carried out during the summer of 1971 for the Inland Waters Branch of Environment Canada involved a spot survey of river and estuarine water quality throughout mainland Nova Scotia. This required many trips in the barracuda convertible that could accommodate four student passengers and sometimes considerably more with the top down.

The objective of this survey was to take and analyze a few water samples from as many locations as possible, not to characterize them based on a limited amount of data but rather to pick out a sample of locations that might merit more detailed study. However, we did make a slightly more detailed assessments of a few locations.

We collected and analyzed approximately 250 water samples for temperature, dissolved oxygen concentration, pH value, colour, turbidity, alkalinity, conductance, hardness, phosphate concentration,

total and nitrate nitrogen, chemical oxygen demand, mercury, copper and zinc and a few of them for coliform count. Geology student Diane Gregory organized and ran the computerized data logging and analysis program. Biology student James Baker performed the coliform tests while field sampling and physical and chemical analyses were carried out by chemistry students Paul MacGillivray, Rick Martin, Glen Roger, Vipin Segal and Ralph Wasson. I did most of the driving and some of the sample collection.

Our Test Results

Our water sample analysis test indicated that the Salmon River in Truro and the Cornwallis River in Kentville were relatively heavily polluted. The Gaspereau River near Wolfville showed a progressive increase in total nitrogen concentration as it meandered through farmland down to its estuary. We noted a general pickup in pollution levels of the Little River as it passed through Sackville and a particularly high total nitrogen level in the vicinity of the trailer park. The Sackville River also showed a jump in its phosphate content after it was joined by the relatively phosphate rich waters of the Little River. The Sackville River showed increasing nitrogen and phosphate levels as it progressed through Bedford. On a more positive note the Annapolis River appeared to be relatively unpolluted.

Footnote

It should be noted that the above observations were based on a limited amount of data, collected for the most part on single occasions. The purpose of this study was to identify and suggest sites for more detailed subsequent study.

OYSTERS IN 1972 AND 1973

Introduction

In 1972 and 1973 I was awarded contracts by the Cape Breton Development Corporation (DEVCO) to carry out studies in support of an initiative to increase oyster culture activity on the Island through its affiliate, Cape Breton Primary Production Limited (CBPPL).

CBPPL staff wanted to know whether the meat of their oysters was accumulating increasing concentrations of heavy metals during their period of growth.

Heavy Metals Analysis

To tackle this problem, we set up a field analytical laboratory in an abandoned bowling alley conveniently located behind Wong's Chinese Restaurant in Baddeck, Cape Breton Island.

In this lab, chemistry students MacDonald and Mader and biology students Lewis and Liu shucked an oyster collection of a range of sizes. After determining their wet and dry weights, they dissolved the meat of the oysters in concentrated nitric acid in glass vials. These samples were shipped back to an SMU analytical lab in Halifax for analysis of heavy metals.

Atomic absorption analyses for various trace metals, but mostly for ion, copper and zinc, were carried out by chemistry students Gay, Lamb and Ling, with general guidance from laboratory assistants Creamer and Munroe.

The relationship between iron content and moist oyster meat weight (Fig 5) indicated that the concentration of iron remained constant as oyster meat weight increased from close to zero to 8 grams. That iron concentration did not increase with growth of the oyster meats was also observed in the case of copper and zinc.

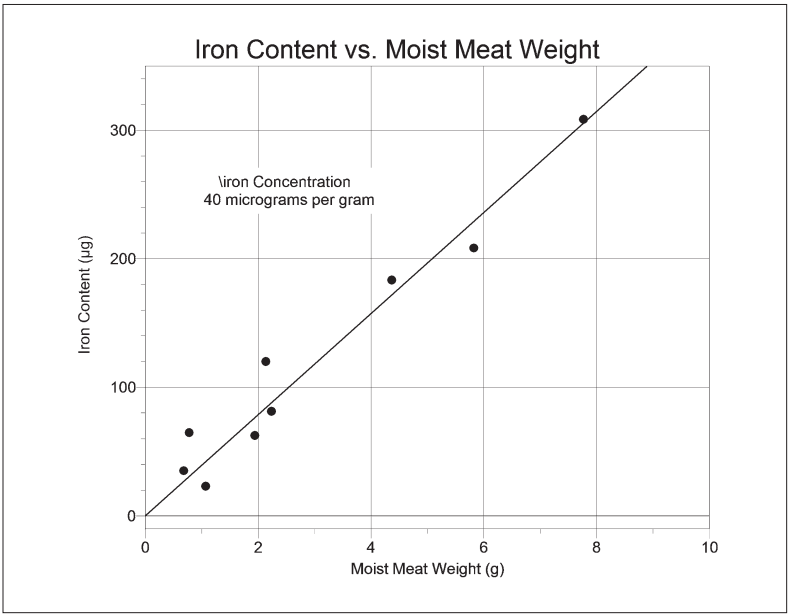


Fig 5 Iron content versus moist oyster meat weight.

A Second Task

CBPPL staff told us that they had observed that oysters grew faster in phytoplankton rich locations and asked us to investigate this relationship.

The Stages of Oyster Growth

Oysters reproduce by releasing eggs and sperm into the water, the fertilized eggs developing into embryos and eventually hatching as free swimming larvae. After a short period, the larvae attach themselves to some solid surface where they become known as spat.

The local oyster farming practice in Cape Breton included making spat collectors. These consisted of a number of scallop shells strung on a string separated by short plastic tube spacers. Illustrated in Fig 6, sets of these strings were hung from rafts that were located above natural oyster beds before spat fall, followed by waiting for nature to take its course.

The subsequent spat growth stage typically takes up to two years. Medcof (1962) described an example of this stage in which spat catching shell strings were set out in July 1960, a few days before spat fall. By November 1960, the spats had grown to an average size of ½ inch,

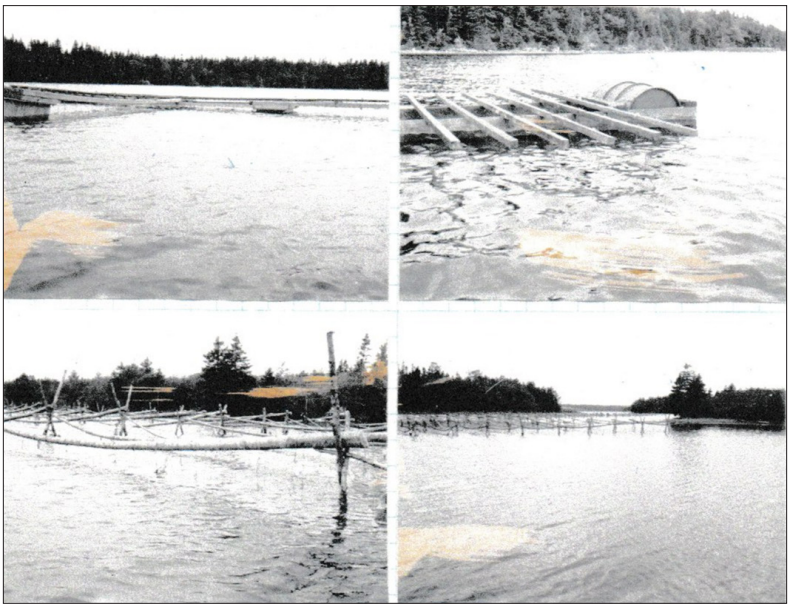


Fig 6 Anchored and moored spat collection setups, Gillis Cove.

with some as large as ¾ inch. By the following November, they had grown to a bedding size of 1½ to 2 inches.

Oyster Growth and the Role of Phytoplankton

Oysters are filter feeders and their primary source of nutrition is phytoplankton. Phytoplankton content levels are commonly determined by fluorometric absorbance analysis of their chlorophyll-a concentration.

Setting Up to Measure Chlorophyll-a

We fitted a high sensitivity door to our laboratory Model III Turner fluorometer (Undated) and followed the fluorometric analytical procedure recommended by Strickland and Parsons (1962) for determining chlorophyll-a concentration as a measure of phytoplankton content.

The Experimental Setup

We arranged for a set of spat collector strings from one particular site to be removed and set up singly at a number of other oyster growing sites and to collect water samples at these sites for chlorophyll analysis. Taken from the same source site, the initial size of the spat was assumed to be the same on the individual test strings.

Finally, before we packed up for the summer, we arranged for our test set of spat strings to be picked up and delivered to our lab in Baddeck. There, we laid them out side by side and tried to arrange them in ascending order of spat size.

Experimental Findings

The range of chlorophyll concentration values observed from the water samples collected at the individual string setup sites at the start of the test period was tenfold but quite small. The subsequent period during which the spats grew on their test strings in the different chlorophyll concentrations was only about two months.

Despite the limitations of the test procedure, the plot of chlorophyll-a site concentration versus spat growth ranking in Fig 7 does show a modest uptrend.

Monitoring Oyster Growth

The progress of oyster growth in the bedding stage is commonly followed by visual inspection or occasionally by weighing selected oysters. It occurred to us that volume is preferable to weight as the parameter for following growth because it is more closely related to the volume contained by the shell halves and therefore the size of the oyster meat.

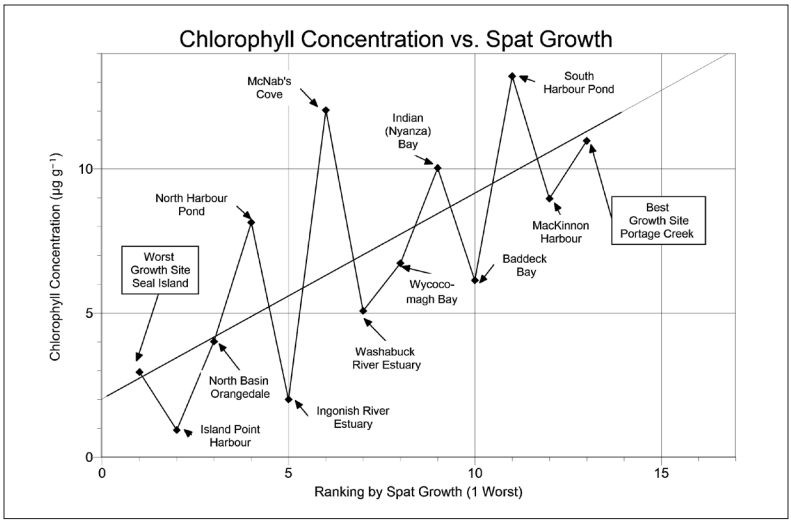


Fig 7 Chlorophyll-a concentration vs. oyster growth.

The problem of accurately determining the volume of an irregularly shaped object denser than water such as an oyster was solved by Archimedes of Syracuse. Archimedes principle states that when an object is immersed in a fluid, it will experience a buoyancy force equal to the weight of the fluid that it displaces.

If an oyster of volume v shows a weight of ρgv in a vacuum, it will show a weight values of $w_{air} = \rho gv - \rho_{air} gv$ in air and $w_{water} = \rho gv - \rho_{water} gv$ in water, from which the volume of the oyster can be calculated:

$$v = (w_{air} - w_{water}) / (\rho_{water} - \rho_{air})g$$
$$\approx (w_{air} - w_{water}) / \rho_{water} g \text{ since } \rho_{air} <<< \rho_{water}$$
$$\approx (w_{air} - w_{water}) \text{ cm}^3 \text{ since } \rho_{water} g \approx 1 \text{ g cm}^3 \text{ in cgs units}$$

With these approximations, the volume of an oyster in cubic centimeters is numerically equal to the difference between its weight in grams in air and when it is immersed in water.

In our oyster volume measuring setup shown in Fig 8, we required a top loading balance, a beaker of water placed on a bridge over the balance pan so that its weight would not be recorded, a deformed wire coat hanger placed on the balance pan so that its weight and anything attached to it would be recorded, some string and some adhesive tape or a metal clip to suspend the oyster specimen from a string attached to the coat hanger, and of course, an oyster.

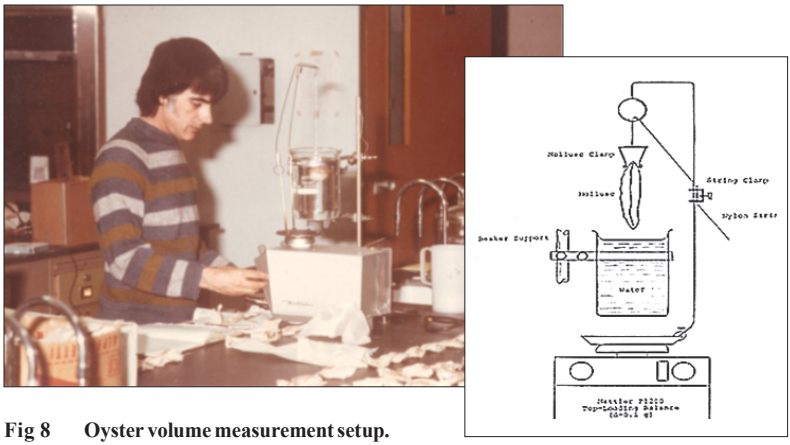


Fig 8 Oyster volume measurement setup.

Small oysters were attached to the string by a metal clip and their volumes were determined from the relationship

$$v = (w_{air} - w_{water}) - (w_{clip,\ air} - w_{clip,\ water})\ cm^3$$

Larger oysters were taped to the string and their volumes were determined from the relationship v = (wair – wwater) cm^3 when each oyster was weighed in air and then lowered to be weighed in water.

Shown in Fig 9, John MacDonald and I made many boat trips during the summer of 1972 to gather water and oyster samples for chemical analysis. We eventually sized and analyzed several hundred oysters from about a dozen bedding site locations.



Fig 9 John McDonald and John Young off on a water and oyster sampling run.

Hardships

I remember two hardships of this project - firstly of overnight sleeping on inflated rubber mattresses on the concrete floor of the bowling alley, and secondly, that Baddeck was “dry” at the time. This meant a trip across the Island in the Barracuda to St. Peter’s to have a beer.

Final 1992 Report

In my 1972 report of our activities to CBPPL, I referred to the recognized desirability of bedding oysters at sites rich in phytoplankton located by chlorophyll-a concentration determination. The suggestion was made that we might be able to develop an automated procedure for mapping such sites.

OYSTERS IN 1973

Setting Up the Fluorescence Recording System

In the summer of 1973, we returned to the Island with, amongst other things, a marine battery, a dc powered pump, a dc-to-ac inverter, a strip chart recorder and a filter fluorometer fitted with a flow-through door. All of this (Fig 10) was assembled on the stern of a Cape Island fishing boat so as to pump lake water through the fluorometer and continuously measure the fluorescence of the chlorophyll-a concentration, representing its phytoplankton content.

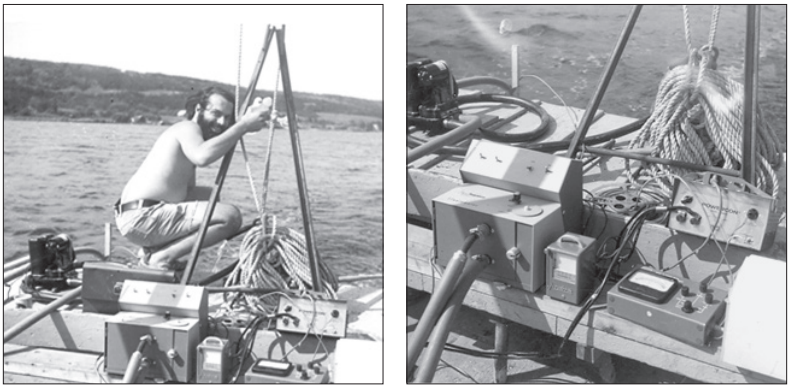


Fig 10 The setup including student John MacDonald. A Chlorophyll-a, Fluorescence Survey.

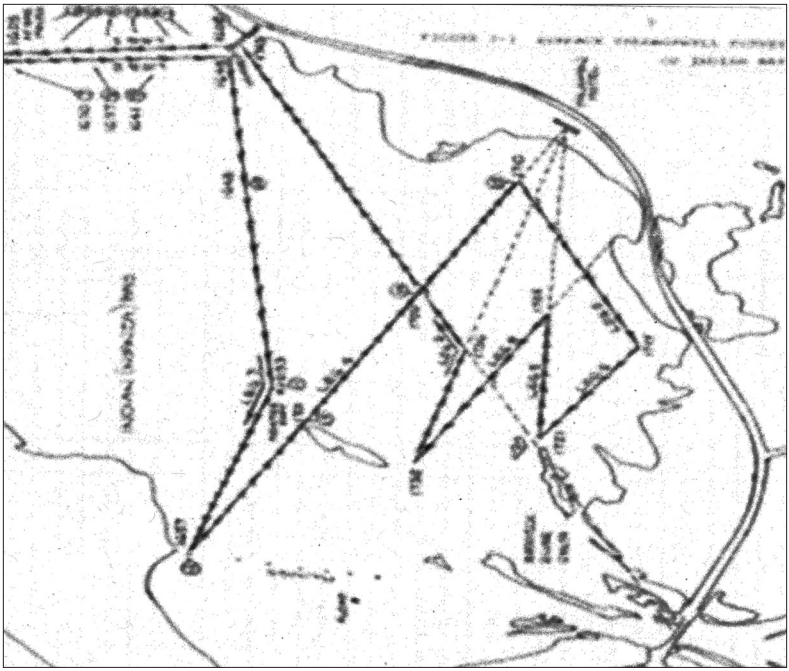


Fig 11 Mapping traverses across Indian Bay.

A Chlorophyll-a Fluorescence Survey

Shown in Fig 11, the fisherman owner piloted his Caper backwards and forwards across the waters of Indian Bay near Baddeck, recording its location at regular time intervals.

Meanwhile, John (M) and I nervously watched the corresponding chart recorder plot of chlorophyll-a concentration fluorescence which for the most part flat lined in the first data sample section shown in Fig 12 which was obtained as we traversed open water approaching the shoreline.

The second section of the data plot (Fig 12) as we travelled along close to the shoreline showed repeated indications of the presence of phytoplankton, particularly towards the right side as we passed for about three minutes over a submerged vegetation bed.in water too shallow to hang spat strings. Evidence of the presence of phytoplankton ceased as we turned back into open water as shown in the third section of the graph (Fig 12).

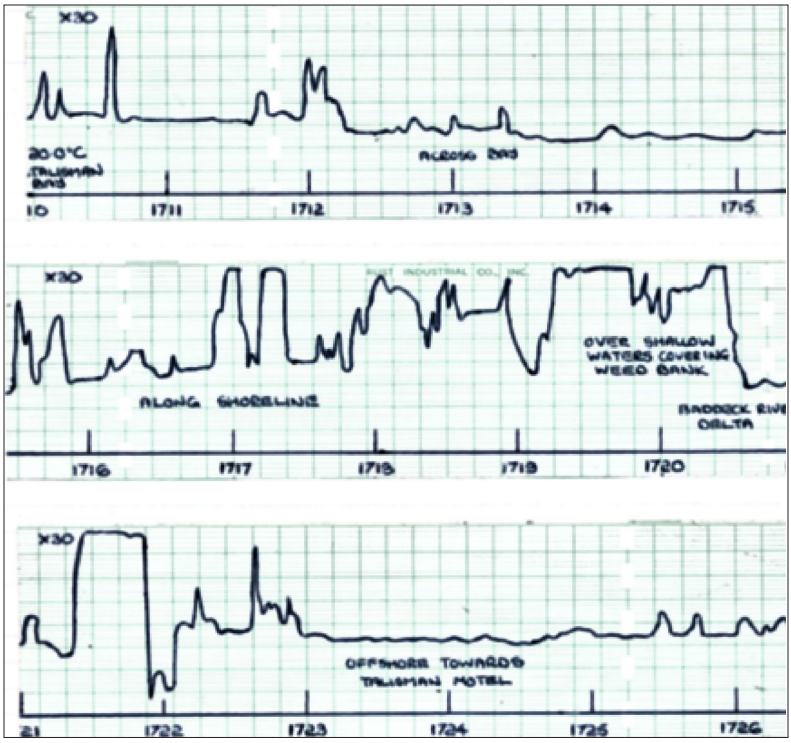


Fig12 Sample plot of the fluorometer reading.

From an aquaculture perspective, this test was unsuccessful because we failed to locate a phytoplankton rich site suitable for hanging strings or bedding oysters. However, operationally it was successful because we demonstrated the location of a patch of phytoplankton growth *in vivo* based on optical measurements of the absorbance of its chlorophyll a content.

We would have liked to carry out tests at other sites but the boat and its skipper were only available to us over a two day period, the first day of which was spent installing and testing the monitoring system. Upon completing our 1993 activity, my students made a study of mussel culture in Cape Breton.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 417-426

LET THEM PARTICIPATE! SCHOOL STUDENTS AS CITIZEN SCIENTISTS AND AGENTS OF CHANGE

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ABSTRACT

Through citizen science initiatives, school students have contributed substantially to scientific knowledge. Often, their contribution is limited to the collection of data and other processes of the research cycle such as developing a research question or disseminating research outputs that are not part of a citizen science initiative. In this article we present the involvement of school students in the citizen science program, Plastic Pirates, investigating plastic pollution of the environment. We project two collaboration opportunities beyond data collection and purely academic work: fitting citizen science initiatives to policy-making processes and engaging with local stakeholders and decision makers. This would ensure that school students as citizen scientists do not only create data and knowledge but experience self-efficacy and step into negotiation spaces, where they are able to act on and engage with the investigated topic at hand.

Keywords: school students, citizen science, self-efficacy, participation in research, decision-making processes

INTRODUCTION

There is much evidence that school students can do science – apart from conducting experiments with a predetermined outcome in the

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classroom. Notable examples are large-scale studies involving school students as data contributors (e.g. Miller *et al.* 2024 for an example from astronomy or Varaden *et al.* 2021 for air pollution monitoring) or studies in which school students came up with a research question and were actually writing and publishing scientific articles (e.g. Blackawton *et al.* 2010, Nicosia *et al.* 2014). Many of such studies are labelled as 'citizen science', meaning that people without a formal scientific education participate in research initiatives led by accredited scientists (see Eitzel *et al.* 2017 for a critical discussion of this term). But it should be emphasized that many school student-led initiatives exist, which have a clear research focus, yet do not fall under the label of 'academic research' (consider, for example, science competitions, hackathons or the makerspace movement).

THE PLASTIC PIRATES CITIZEN SCIENCE PROGRAM

The citizen science program we (the authors TK, SD, JS) coordinate has involved more than 25,000 school students over the past decade in Germany (Dittmann *et al.* 2023). The initiative, called 'Plastic Pirates' (plastic-pirates.eu/) includes school students in the research of plastic pollution in aquatic environments. The Plastic Pirates initiative is based on the citizen science program Científicos de la Basura ('Litter Scientists'), active since 2007 in Latin America (Thiel *et al.* 2023), and has since been extended to other European countries (Uogintė et al. 2024) and to Nova Scotia in Canada as a pilot project (Kiessling *et al.* 2025).

So far, the school students investigated more than 1500 sampling sites in Germany, classified thousands of litter items and identified potential litter sources (Dittmann *et al.* 2024; Fig 1). The research data they collected also allowed us to evaluate a European policy instrument to curb plastic pollution (Kiessling *et al.* 2023), highlighting the potential to address novel challenges through citizen science. While many of the school students' research findings have been published, a provocative follow-up question would be: Do the school students actually care about academic research articles? While the value of their research contribution is obvious to us and fellow scientists, research outputs are commonly presented in a format that remains out of grasp for the school students and their teachers.

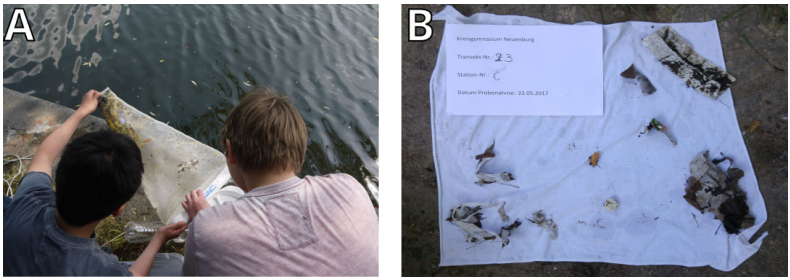


Fig 1 **(A) School students handle a sampling net, used to capture small plastic particles (microplastics). Photo by Bertha-von-Suttner Gymnasium Berlin. (B) A photograph used by Plastic Pirates researchers for data quality review, comparing litter items in the photo with those annotated on data sheets submitted by school students or teachers. Photo by Kreisgymnasium Neuenburg.**

FROM KNOWLEDGE CONTRIBUTION TO CO-PRODUCING CHANGE

We undertook some efforts to make research resulting from the contributions by the school students more accessible to them, for example in the form of short videos (youtube.com/watch?v=tM4J07gzxhw, in German) or social media updates showing ongoing research processes. Yet, the Plastic Pirates can be seen as a largely 'contributory' citizen science initiative (Senabre Hidalgo *et al.* 2021), meaning that school students are mainly involved in large-scale data collection and rarely participate in further phases of the research cycle (such as data analysis or knowledge dissemination). Similarly, though the related educational material (plastic-pirates.eu/de/material/download) offers additional exercises and instructions for project-based work to address the topic of plastic pollution after participation in the citizen science program, it is up to the teachers, and available space in an oftentimes busy school environment, to implement these further steps. Further, a study (Kruse *et al.* 2020) related to the predecessor project of the Plastic Pirates investigated changes in self-efficacy of the participating school students, meaning an individual's belief to act out of their own capacity to address a relevant goal or problem (in this case plastic pollution): It showed that school students did not increase their perception of self-efficacy after participating in the citizen science program (Kruse *et al.* 2020). We suspect two possible causes; the ubiquitous and global scale of plastic pollution might be overwhelming, or school students did not relate their research contribution to advancing on solving

plastic pollution. Either way, there is a need to discover pathways to relate the participation of school students in citizen science to real-world changes. In our opinion, this might happen through opening up collaboration opportunities at (i) a supranational level relating to legislation by the European Union, and (ii) a local level involving relevant stakeholders and decision makers.

ENABLING CHANGE THROUGH ENGAGING WITH PLASTIC POLLUTION LEGISLATION

In a recently published article we suggested how data originating from the Plastic Pirates program could inform the Water Framework Directive of the European Union (Schönberg *et al.* 2025). The Water Framework Directive has the goal to achieve healthy aquatic environments but does not yet consider plastics as a relevant source of pollution (e.g. Black *et al.* 2019). The already existing Plastic Pirates data in Germany and other European countries could be used as a baseline to inform this directive regarding the integration of plastic pollution (Fig 2A, B). Further, in the future, citizen scientists could collect valuable data, complementary to the directive, for example by identifying pollution hotspots (Kiessling *et al.* 2021, Schönberg *et al.* 2025, Fig 2C). This approach, to systematically consider citizen science research outputs for the formulation, evaluation and improvement of this and similar directives would give citizens an engagement opportunity with high-level pieces of European policy-making (Oturai *et al.* 2023). It would also fulfil a self-imposed obligation of many such directives to involve citizens in meaningful ways (e.g. 'The success of this [Water Framework] Directive relies on close cooperation and coherent action at Community, Member State, and local level, as well as on information, consultation and involvement of the public […]', EU Directive 2000/60). The road to interlock citizen science and policy-making can be long and stony, as a case study about the uptake of publicly collected plastic pollution data in official reporting of the Sustainable Development Goals in Ghana showed (Fraisl *et al.* 2023). But the need for this is urgent: more than half of citizens believe that their voice does not count in the European Union and only 15% find it feasible to participate in European Union policy-making (Hierlemann *et al.* 2022). Key questions concern how to harmonise data sources with legislative requirements and how responsibilities can be shared

among diverse stakeholders, including citizens and, hopefully, school students (Schönberg *et al.* 2025).

ENABLING CHANGE THROUGH ENGAGEMENT OF LOCAL STAKEHOLDERS AND DECISION-MAKERS

Moving beyond data collection also means increasing the data literacy of school student, their capacity to draw data-based conclusions and to invite them to disseminate their knowledge (compare to Phillips *et al.* 2021 on building 'social capital'). Subsequently, school students could act as 'agents of change' to enter previously closed negotiation spaces in order to engage more effectively on the issue at hand. As an example, school students in Rendsburg (in northern Germany) who had participated in a waste audit of their school yard presented their findings on posters (Fig 3). The school principal attended the

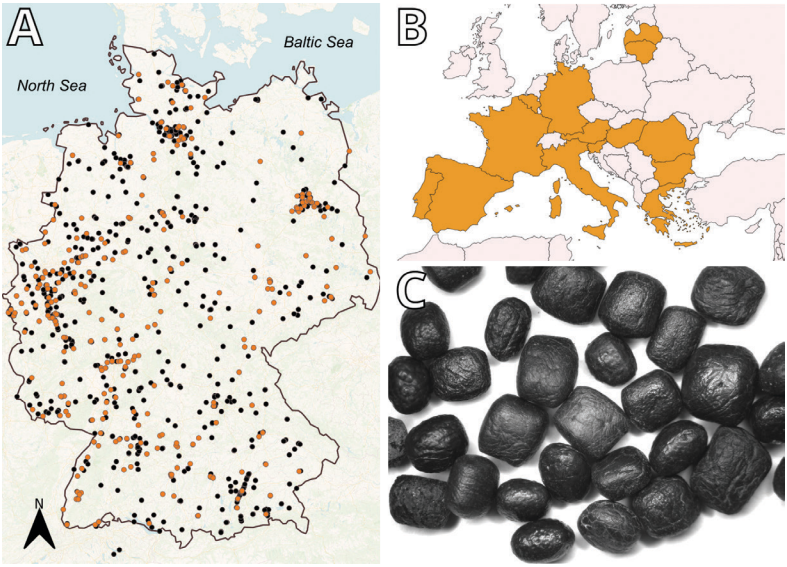


Fig 2 **(A) About one third of Plastic Pirates sampling sites in Germany (yellow dots) are already located within 1 km of a Water Framework Directive monitoring station. Fig from Schönberg *et al.* 2025, Creative Commons license CC BY 4.0. (B) European countries (in orange) participating in the Plastic Pirates program, showing the potential for large-scale data collection. (C) Microplastic particles from a river hotspot discovered by school students from Sekundarschule Schkopau. Photo by Magdalena Gatta-Rosemary/Kieler Forschungswerkstatt, Creative Commons license CC BY 4.0, first published by Kiessling *et al.* 2021.**



Fig 3 **(A) Litter collected in the schoolyard during a waste audit at the school Helene-Lange-Gymnasium Rendsburg. (B) Poster by school students presenting outcomes of the waste audit, focusing on single-use plastics. Photos by Tim Kiessling, Creative Commons license CC BY 4.0.**

poster presentation and related the research outcomes to the mayor of Rendsburg, who subsequently invited the young citizen scientists to a meeting to discuss potential solutions to the unhealthy consumption of packaged food products at their school (Flender *et al.*, in preparation). This civic engagement does not purely have an activist point of view, but is based on research data. The extensive occupation with a research topic also ensures a deeper understanding of the issue at hand. As another, larger-scale example, the schoolchildren of the Latin American Científicos de la Basura ('Litter Scientists'), have implemented 'environmental actions' related to plastic pollution after being involved in a citizen science study (cientificosdelabasura.ucn.cl/acciones-ambientales/). We assume that there might be other potential impact avenues, for example using municipality-backed sustainability initiatives as a leverage for increased and sustained engagement (such as the Zero Waste City certification in Europe, zerowasteeurope.eu/certification/) or harnessing the potential of favourable press and media attention (more than 2,000 media articles were published about the Plastic Pirates initiative and the research work by the school students, Dittmann *et al.* 2023). Key questions revolve around the identification of local decision makers (e.g. school principals, local politicians), and how to systematically establish collaborations and how to measure impacts.

OUTLOOK: POTENTIAL IMPACT OF TRANSFORMATIVE CITIZEN SCIENCE

Strong legislation as well as effective local action is needed to provide solutions to the ever-growing plastic pollution crisis, especially in the light of failing United Nations negotiations and powerful industry actors sabotaging solutions (Ralston and Taggart 2025). The citizen science approach, democratizing access to knowledge production, can act as a door opener for this and other societal problems, with the subsequent outlook of citizen scientists stepping into negotiation spaces. Currently, there often remains a disjunction between citizen research actors collecting data and the data itself, which is interpreted and used by academic researchers. In this article we suggested to keep involving citizen scientists beyond the phase of data collection, so that they can become agents of change. We argue that this would be especially beneficial for school students who work and learn in a performance-oriented school environment and have rare chances to meaningfully transform their environment due to a lack of financial means and political representation. Implementing school-based citizen science initiatives and adding civic engagement components could present a unique opportunity to increase their self-efficacy and become engaged and confident societal actors. We adults and academic researchers need to ensure that school students can step forward, take up space and be at the center as the initiators and leaders of change.

Acknowledgments We are indebted to thousands of school students and teachers who have made the Plastic Pirates what they are today. We apologize that we have not yet found adequate acknowledgment mechanisms beyond anonymous statements such as this one. We further want to point out that even this call for courage to open up spaces for school students remains (for now) yet another academic article, with limited relevance to the living realities of our young co-researchers.

FUNDING INFORMATION

Work leading up to the writing of this article was funded by the former German Federal Ministry of Education and Research (BMBF), by Kiel University – "Zukunftsvertrag Studium und Lehre stärken" and by the Ocean Frontier Institute's Visiting Fellowship Program 2024.

The writing of this article remained unpaid; all authors volunteered their spare time.

FURTHER INFORMATION

This article is based on a previously published blog article, titled "Can Schoolchildren Contribute to Research and Policy-making Through Citizen Science?", eiui.ca/can-schoolchildren-contribute-to-research-and-policy-making-through-citizen-science/

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 427-439

THE WORKS OF THOMAS HUGH "TOM" NEILY, NOVA SCOTIA FIELD NATURALIST EXTRAORDINAIRE

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Thomas H. "Tom" Neily was one of Nova Scotia's premiere field botanists and naturalists. His contributions to documenting the vascular plants, lichens and bryophytes of the province were on par with some of the province's best-known botanists of the last century, like A.E. Roland, E.C. Smith, and J. Erskine. Tom passed away on March 14, 2026, at the age of 68. This article summarizes his professional life and work from the perspective of those who were fortunate enough to have worked closely with him.

Born in Spa Springs, in Nova Scotia's Annapolis Valley in December 1957, Tom's rural childhood produced a strong interest in natural history. After high school, he attended the Agricultural College in Truro for two years, then went on to McGill University in Montreal. After receiving his degree in Plant Science (BSc, 1980), he worked as a landscaper for a few years and then as a baker, with a special talent for cheesecake (Chris Pepper, pers. comm., May 28, 2026), before returning to Nova Scotia.

In the 1990s Tom continued working as a baker while living in the Centre Burlington area of Nova Scotia. It was during this time he connected with Marian Munro, who worked at the herbarium of the Nova Scotia Provincial Museum (NSPM), through mutual friends. Tom was soon doing contract work and volunteering with the NSPM herbarium. When Marian became the Curator of Botany at the NSPM she passed her botanical consulting clients over to Tom, helping him to launch his career as a contract field botanist (M. Munro, pers. comm., March 18, 2026).

One of the first consulting projects Tom participated in was an environmental assessment for the proposed White Rock Mine in Yarmouth

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County (which was later rejected by the government as being environmentally risky for the nearby Tobeatic Wilderness Area), along with Ruth Newell, Heather Stewart, and colleagues from Dillon Consulting Ltd. (Black Bull Resources Inc. 2001). From then on, Tom regularly took on contracts for Dillon and other consulting firms, including Stantec, East Coast Aquatics, AMEC, CRA, and CEF Consultants Ltd. Projects on which Tom contributed plant or lichen surveys included the Lingan Wind Farm (Dillon Consulting Ltd. 2005), the Melford Container Terminal (AMEC Earth and Environmental Ltd 2008), the Moose River Gold Mine (Conestoga-Rovers & Associates 2007), the Amherst High Pressure Steel Distribution Pipeline (Dillon Consulting Ltd. 2004), a creek realignment in Cape Breton, several highway expansion projects (CBCL Limited 2018, Dillon Consulting 2017, Stantec Consulting Ltd. 2017a, 2017b), and multiple projects for Department of National Defense properties.

The work for which Tom is best known was with rare and at-risk lichens. In 2003, Tom was contracted by Nova Scotia Departments of Environment and Natural Resources to conduct surveys for the endangered Boreal Felt Lichen (BFL), *Erioderma pedicellatum*. This program later evolved into BFL monitoring through the Mersey-Tobeatic Research Institute (MTRI, Fig 1). Early on Tom proved himself an exceptional field lichenologist, finding many new locations for Boreal Felt Lichen, but also many other rare lichens. The first years of lichen work focused on the Eastern Shore region, where Tom revisited BFL finds annually, spending long hours documenting survival, health, habitat parameters and any habitat changes. Tom discovered over 85% of the known BFL population (over 400 new host trees). His discovery of the so-called Supertree, a mature balsam fir covered in 35+ thalli (MTRI 2008), drew national media attention (Barron 2010). He later did similar survey work for Vole Ears Lichen (*Erioderma mollissimum).* His GPS tracks of lichen searches recorded over 8000 km of walking on foot through often swampy woods, done largely in the fall or winter, often in rainy, wet or even snowy weather. He once described this time of year as ideal for such surveys, as he was "less likely to get wet feet" (Tom Neily, pers. comm. to Stephen Clayden, Feb 12, 2007).

The invaluable data Tom collected led to many studies of the population size, habitat affinities, and threats to BFL, as well as the creation of several predictive habitat models for BFL and other lichens (Cameron 2021, Cameron and Bayne 2020, Cameron, Goudie, *et al*. 2013, Cameron

and Neily 2007, 2008, Cameron et al. 2010, 2011, 2007, Cameron, Neily, *et al*. 2013; Cameron and Toms 2016, Haughian *et al*. 2022, Pearson *et al*. 2018, Power *et al*. 2018). His work was also foundational for most of the COSEWIC reports on eastern Canadian at-risk lichens in the last 20 years (COSEWIC 2010, 2014, 2015, 2016, 2019, 2021). Eventually, the work of Tom and others on lichen monitoring and inventory led to the establishment of the first lichen special management practices (SMPs) for forestry in Canada, including the protection of core habitat and the requirement to conduct pre-cutting lichen surveys of potential BFL habitats (Province of Nova Scotia 2018). His tireless work over the course of 15+ years greatly increased what is known and understood about Boreal Felt Lichen and other rare cyanolichens in Nova Scotia and led to the establishment of multiple protected areas for rare lichens in the province.

Tom's work with BFL inventory and monitoring, combined with his reputation as an excellent field naturalist, also connected him with other lichenology professionals and projects throughout Atlantic Canada. He began corresponding with Stephen Clayden, Curator of Botany at the New Brunswick Museum (NBM), in 2004 when he sent several lichen specimens to Stephen. He subsequently took Stephen's course on lichen identification at the Humboldt Field Research Institute (now the Eagle Hill Institute) in Steuben, Maine, and their correspondence continued periodically thereafter. Tom attended several forays to the island of Newfoundland to study Boreal Felt Lichen sites with Newfoundland species at risk botanist Claudia Hanel (C. Hanel, pers. comm., May 26, 2026), and along with Rob Cameron (former Ecologist for the Dept. of Environment), discovered the first Newfoundland occurrence of Vole Ears Lichen on one such trip (Jørgensen *et al*. 2009). Tom also attended the first Boreal Felt Lichen research conference at Memorial University and contributed to the first provincial lichen status assessment in Canada (Anderson 2007). A contract between MTRI and the Nova Scotia Department of Natural Resources enabled Tom and Frances Anderson to document lichens found in the unique karst ecosystems around Nova Scotia (Anderson and Neily 2010), a collaboration that continued through many additional projects (e.g., Anderson & Neily 2012). In 2005, Tom and Robert Cameron spent several weeks surveying macrolichen communities in Halifax to understand the effects of pollution (Cameron *et al*. 2007); their study was later expanded to include a network of permanent lichen sampling plots across NS (Cameron 2022).



Fig 1 Tom in the field. Photo by Amanda Lavers, MTRI, 2008.

Although Tom was interested in all plants and lichens, certain taxonomic groups and habitats were among his favourites. Tom's interest in bryophytes began in the early 2000s at the urging of fellow naturalist and friend, Harold Clapp. This interest was enhanced by his attendance at an introductory course held at Acadia University's E.C. Smith herbarium in 2005, given by University of Alberta's Rene Belland. According to fellow attendee Sean Basquill of Nova Scotia's Department of Natural Resources,

> *"While some students in Belland's course wanted tips on the fastest or singularly most reliable way to identify a species, that wasn't Tom. Tom wanted to know it all, and he wasn't interested in short cuts. Equally comfortable in the field or behind a microscope, Tom was incredibly fastidious with all aspects of specimen collection and identification."*
> *(S. Basquill, pers. comm. May 11, 2026)*

Subsequent attendance at week-long courses at the Eagle Hill Institute on liverworts, *Sphagnum*, and other bryophyte groups, provided Tom with a solid background in what he considered the undervalued members of the botanical world.

One bryophyte group that became a specialty of Tom's was the peat mosses. Between 2009 and 2020, he collected and identified over 2000

Sphagnum specimens, including four new provincial species records, two of them new to Canada. Most of these specimens were donated to the L.E. Anderson Bryophyte Herbarium at Duke University, inspired by two of his early mentors in *Sphagnum* biology, A. Jonathan Shaw and Blanka Aguero. Along with colleague and friend Harold Clapp, Tom discovered a second population of the rare *Sphagnum cyclophyllum* in 2016 (Clapp and Neily 2017), leading to its eventual assessment for federal protection and a recommendation for listing as an endangered species (COSEWIC 2024). His deep knowledge of this genus in Nova Scotia culminated in a recent monograph (Basquill *et al*. 2024).

Tom's knowledge of peat mosses and vascular plants also placed him in a unique position for contributing to environmental assessments (especially wetland delineations), monitoring peatland vegetation plots in Kejimkujik National Park, and for specialised projects such as the palaeoecological reconstruction of Big Meadow Bog on Brier Island, NS, in 2016 (Spooner *et al*. 2017). According to collaborator Nick Hill,

> *"Tom was able to apply his rigour to search out… millimetre scale Sphagnum leaves still preserved in the peat to reconstruct the succession of the wetland... Tom's expertise, scientific method and patience led to the understanding that Big Meadow Bog went through marsh stages before it became a treed swamp, a fen with S. affine, and finally a raised bog with the loss of S. affine and dominance of Section Acutifolia." (pers. comm. May 11, 2026)*

Tom was a prodigious specimen collector. In Nova Scotia alone, the ACCDC database includes over 13,564 of his observations, largely of lichens (6426 records) and bryophytes (4371 records) with most collected between 2000 and 2020 (ACCDC 2026). These records include over a thousand different species, including dozens of new provincial records and a few national ones (Haughian and Neily 2019, Neily and Anderson 2010, Neily *et al*. 2024). Tom also collected extensively in New Brunswick and PEI during his work on an Atlantic Ecosystems Initiative project with the ACCDC (Mazerolle *et al*. 2018), and made several trips to Newfoundland, where he contributed to both botanical inventories and critical habitat mapping for the Threatened Porsild's Bryum (COSEWIC 2017). Many of Tom's specimens are at the EC Smith herbarium (~4000 specimens), the NB Museum (~1500 specimens), and the Nova Scotia Museum (~1500 specimens).

In 2018, Tom began to take a more dedicated interest in the bryophytes and lichens of anthropogenic habitats, particularly around agricultural fields or orchards. This was timely, as in the spring of 2019 he was diagnosed with the serious illness that he contended with for the next several years, and that prevented him from hiking for long periods. During this time, he spent many hours riding his bicycle or driving his jeep through Nova Scotian farmland, documenting rare and previously undetected species. He frequently exchanged information and microscopic photos with his colleagues over email. In one such correspondence, he wrote:

> *"I have been able to work on my arable bryophytes... I can manage this habitat quite well and there is plenty of it here in the Valley, so I don't travel far. I get out most days surveying new fields. It is the margins that are important and they are easily accessed. This work is quite pleasant actually and timely given the circumstances. I am surprised by the diversity and the seasonal changes. In May, Physcomitrium pyriforme was in practically every field. It is no longer visible but replaced by P. immersum. I have found a new Ephemerum record for the province, E. crassinervium but it would have easily been overlooked. I had been struggling with one particular nondescript species but finally got it this week, Trichodon cylindricus. The tuberous Bryum species are benefiting these days with the cooler temperatures and damp conditions. Dicranella, Weissia and Barbula species are frequent. I have several Phaeoceros sites and the Fossombronia spores are now ripe. The one I see is F. wondraczekii." (Tom Neily, pers. comm. to Stephen Clayden, March 10, 2019)*

During this difficult time he nevertheless accumulated nearly 1000 additional specimens, and nearly 3600 iNaturalist records, mostly from within a few steps of a road. This work in arable and anthropogenic habitats also inspired a research project examining the relationship between bryophyte communities and proximity to field margins (Kernaghan 2025, Kernaghan *et al*. 2026).

Although botanical and lichenological inventory remained Tom's passion throughout much of his career, he was also a generous conservationist who volunteered his time in service of threatened species and ecosystems outside of work. He served on the Province of Nova

Scotia's Lichen Recovery Team from its inception until 2023, offering advice and sharing his experience with representatives of government, industry, and nonprofit organizations. Tom regularly participated in volunteer plant and lichen surveys for conservation organizations such as the Nova Scotia Nature Trust, the Nature Conservancy of Canada, and Parks Canada (Chapman *et al*. 2020, Hill *et al*. 2012, McMullin *et al*. 2019). He contributed his expertise in support of developing subnational species ranks for three Wild Species Reports (Canadian Endangered Species Council 2011, 2016, 2021). He was also a long-serving volunteer at the E.C. Smith Herbarium, and a Research Associate at the Nova Scotia Museum's Herbarium from 2018 to 2026, contributing much time to specimen preparation, verification, and cataloguing. Perhaps the clearest demonstration of his commitment to these institutions was in 2023-2024, when he continued visiting the NSM Herbarium to help with specimens while staying in Halifax for cancer treatment (S. Haughian, pers. comm., May 26, 2026).

Tom's generosity was also apparent in his willingness to mentor beginners in field lichenology or bryology. He regularly invited such beginners on his forays into the woods and wetlands and helped them with species identifications (Fig 2).

> *"He was a great teacher; I probably owe my consulting career to him more than anybody. Besides being a fantastic botanist and mentor, I was always amazed how well he knew his way around the province, and how many people remembered him. I always got a kick out of random people in random towns approaching him and asking, 'are you still looking for that moss, Tom?'" (Chris Pepper, pers. comm., May 28, 2026)*

> *"He took a genuine interest in the professional development of junior staff, generously taking the time to help others hone our plant identification skills in the field... Anyone who went into the field with Tom knew he walked way too fast! Trying to keep up with him was always an adventure."*
> *(Kelly Regan, Dillon Consulting, pers. comm. May 19, 2026)*

According to his colleagues, Tom was a genuine pleasure to work with, with a great sense of humour, ample humility, and a willingness to share his knowledge. His personal qualities and impressive abilities left a lasting impression on many of us. Those who spent time with him describe Tom best in their own words:

"I remember Tom's find of the first Blue Felt Lichen in Nova Scotia. He didn't want to hazard a guess as to what it was he'd found and called David Richardson and myself to have a look. I think Tom had already known what it was but in that humble way of his, sought confirmation. David quickly identified it as Blue Felt Lichen." (Rob Cameron, pers. comm., May 8, 2026).

"There's so many good things I could say about Tom. His vast knowledge about the natural world, his almost uncanny ability to spot a rare moss or lichen or navigate through the woods and find the best habitat… But what I will remember most about Tom was his generosity in sharing his knowledge with me." (Harold Clapp, pers. comm., March 19, 2026).

"Tom radiated curiosity and kindness… I will happily remember the too-few times we got together in the field and herbarium, his impish sense of humour, and our long-running correspondence." (Stephen Clayden, pers. comm., June 16, 2026).

"Tom's knowledge and enthusiasm were infectious. He was a brilliant natural historian and a most gracious and humble person." (Terry Power, pers. comm., March 21, 2026).





Fig 2 **(Left) Tom with Ruby Todd, photo by Jim Todd, courtesy of MTRI; (right) Tom with Frances Anderson during a visit to the New Brunswick Museum, photo by Stephen Clayden.**

Tom's personal life similarly reflected his strong conservation ethic and generosity. He lived for many years in an off-grid, straw bale house on the Annapolis Valley's North Mountain, with only a wood stove for heat; he used a solar panel to charge his laptop and a battery which gave him a little light in the evenings. Tom was fond of antique furniture and books, because he admired the superior quality and longevity of well-made things. He also embraced a largely vegetarian diet to ease his impact on the environment. Most of Tom's home laboratory equipment and reference books have been donated to the Nova Scotia Museum for use in teaching natural history courses. In death, as in life, Tom continues to support and inspire budding naturalists, to foster a conservation ethic in others, and to cultivate an intense appreciation of the natural world among his colleagues and friends. We bid him a fond farewell.

Acknowledgements We wish to thank the many colleagues who shared with us their experiences, memories, and publications from working with Tom. Their contributions may be read at www/merseytobeatic.ca/tomneily. In particular, we thank S. Basquill, R. Cameron, H. Clapp, S. Clayden, N. Hill, M. Munro, C. Pepper, T. Power and K. Regan, who were quoted directly in this paper, and A. Lavers, S. Clayden, the MTRI, the ACCDC, the NBM, and the NSPM, who contributed photos or data. We also thank Tom's family for entrusting us with the privilege of preparing this tribute.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 441-443



REMEMBERING DR. ROBERT (BOB) H. COOK – NSIS COUNCIL MEMBER AND AQUACULTURE SPECIALIST EXTRAORDINAIRE

Dr. Robert (Bob) Cook, a former very active NSIS Council member, passed away recently (January 2026). He had a very successful career as a federal government marine scientist and administrator, and a long and active retirement from his home at Portuguese Cove on the outskirts of Halifax.

Post retirement, Bob served the NSIS Council in various roles. He was a full Council member, coordinator of the student writing competition from 2008-2012, a member of the NSIS 150th Anniversary Committee, 2010-2012, and a member of the Hall of Fame Nominations Committee 2011-2012 (M. Paon, pers. comm.). Bob was also an active member of the BIO-Oceans Association (BIO-AO) in its early days, contributing to its meetings and Newsletter (Cook 2008). He is remembered as being an energetic and pleasant person, always with a smile and a great sense of humour, and always with a positive contribution to the programs of both organizations.

I (pgw) personally knew Bob while we both worked for the Environmental Protection Service (EPS), Environment Canada (EC), in Dartmouth, NS. He interviewed and hired me back in 1973 while I was completing my Ph.D. research at the St. Andrews Biological Station (SABS) and the newly formed Huntsman Marine Laboratory. He was my senior EC manager for three years (1974-77), overseeing our marine pollution control programs (aquatic toxicology, microbiology, analytical chemistry) at the Bedford Institute of Oceanography during

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the early years of EC. He was very supportive of our pollution programs and efforts in those days.

Although primarily a program manager, he was very active in our field water monitoring, as he was an expert and experienced scuba diver. He obviously loved marine field work. He had obtained one of his graduate degrees at Dalhousie, an MSc. in oceanography (1963 to 1965) and later a Ph.D.

After working for EPS, in 1977 Bob moved on to positions in the federal Department of Environment and Fisheries, and the newly formed (1979) Department of Fisheries and Oceans (DFO), serving as Director of SABS from 1977 to 1992. Hubbard (2016) summarized his many contributions to the conduct of SABS and importantly to marine aquaculture in Atlantic Canada. He was very engaged nationally and internationally in promoting the open pen (sea cage) salmon aquaculture industry in the Bay of Fundy region and was responsible for the Salmonid Demonstration and Development Farm Project in the 1980s. He was the first President of the Atlantic Aquaculture Fair. Bob also served on the St. Croix International Joint Commission (IJC) Water Quality Committee from 1979 to 1992 and on the Atlantic Fish Habitat Task Force (Wells 2016). He was a long time contributor to the Mariculture Committee of ICES (International Council for the Exploration of the Sea) (Cook 2016).

After St. Andrews, Bob moved in 1992 to Nova Scotia and was director of aquaculture coordination at DFO in Halifax until his retirement in 1998 (Hubbard *et al*. 2016). Besides being involved in the NSIS and the BIO-OA, he gave a fine overview of the salmonid aquaculture industry at the 2008 SABS centennial event (Cook 2010) and contributed to the book on the history of SABS – *A Century of Maritime Science* (Hubbard *et al*. 2016.).

Our Maritime coastal community and the NSIS have lost yet another fine scientist and contributor. He will be greatly missed but much remembered – his service to the NSIS, his scientific contributions, and his smiles and endless positivity will last a very long time.

Acknowledgements Dr. Jennifer Hubbard's 2016 book was invaluable in retrieving "nuggets" about Bob's career, pointing once again to the huge value of having scientific histories. Thanks are also due to Michelle Paon (of the NSIS) and Jennifer Mudge (of the BIO Oceans Association) for assistance finding some key information for this article.

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Peter G. Wells
Editor, PNSIS, and Dalhousie University

Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 445-470

SHORE ARMOURING ON THE NORTH SHORE OF MAINLAND NOVA SCOTIA

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Dedicated to Anthony Miller:
friend, colleague and avid naturalist

ABSTRACT

Using Google Earth (GE) and ground proofing of selected shorelines, we mapped coastal defense measures (CDMs), along the coast of the Northumberland Strait of Nova Scotia from the New Brunswick border to the Canso Causeway. An initial method used 256 point samples from Tidnish to Cape George at 0.5' of longitude and revealed a 22.8% occurrence of armouring. A second method used GE images and the 'path' tool to trace the lengths of each individual wall along 15 shoreline segments facing the Northumberland Strait and selected bays and estuaries. This identified 218 individual CDMs with the most frequent 51-150 m long and four continuous walls over 1000 m long. Shores had 3% to 74% armouring with enclosed estuaries generally having lower values and the outer, exposed shores having higher values. Short lengths of armouring (i.e., less than 50 m) were generally associated with individual residential properties. The impacts of CDMs are discussed in relation to coastal and vegetation changes on shorelines of northern Nova Scotia. Several case studies including original observations at Northport, Big Island, and Mahoneys Island demonstrate for the first time in eastern Canada how CDMs have modified coastal habitats, specifically sand dune and salt marsh ecosystems.

Keywords: armouring, beaches, climate change, sea-level rise, seashore erosion

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INTRODUCTION

Sea-level rise and consequent seashore erosion are global phenomena. While the ultimate cause is climate change, specific contributors include melting of glaciers on both poles, thermal expansion of water, and runoff from terrestrial systems (Munk 2003, Cazenave and Nerem 2004, IPCC 2023, Houston 2024, Chandanpurkar *et al.* 2025). Recent evidence suggests that the rate of sea-level rise has doubled over the last three decades (Hamlington *et al.* 2024), with a record rise of 5.9 mm globally in 2024 (Hamlington *et al.* 2025). The general impact of sea-level rise has been extensive seashore erosion and coastal flooding that impacts both natural habitats and the built environment (Gracia *et al.* 2018).

This global phenomenon is exacerbated in the southern Gulf of St. Lawrence because of post-glacial subsidence (Grant 1975, Scott *et al.* 1987, Carter *et al.* 1989, 1990, Gehrels *et al.* 2005, Han *et al.* 2015) where recent rates of sea-level rise are at least 3-4 mm per year and may be accelerating (Boon 2012). The gentle slopes of most of the coastline and the associated regional geology in the southern Gulf of St. Lawrence with soft rock (i.e., sandstone) make these shorelines particularly prone to erosion (Finck 2007a, b) relative to shores with steeper slopes and harder bedrock (i.e., granite) along the Atlantic coast of Nova Scotia (Roland 1982, Shaw *et al.* 1998). In addition, the microtidal dynamics of the southern Gulf of St. Lawrence result in lower sediment deposition relative to shores of the upper Bay of Fundy. Together, these features have combined to effect conspicuous shoreline erosion on the north shore of mainland Nova Scotia relative to the rest of the province. Taylor *et al.* (1985) suggested shoreline retreat of 0.7 m y^{-1} along the Northumberland Strait; Forbes *et al.* (2004) determined shoreline retreat of >0.5 m y^{-1} for the north shore of Prince Edward Island. These changes have been recognized as part of climate change risk assessment for Nova Scotia (Anonymous 2025).

The warm summertime water and extensive sandy beaches make the north shore of Nova Scotia attractive for summer residences. Indeed, much of what was historically agricultural land has been transformed in the last century into densely packed cottages, resorts, campgrounds, and golf courses. There are remnant farm and forest landscapes; however, the scattered villages and towns are typically found within the harbours and estuaries that have been formed as drowned river valleys. Given climate change over the last 65 years (Garbary 2018, Garbary and Hill 2021) with its decrease in winter ice (Galbraith *et al.* 2024,

Ollerhead 2024), increase storm activity (Garbary and Hill 2025), and their stochastic nature (Ollerhead 2024), it is not surprising that property owners either alone or in groups have needed to protect their investment by constructing coastal defense measures (CDMs) (Figs 1 and 2; Bernatchez and Fraser 2011). Shore armouring is regulated in part by federal policy under the Fisheries Act (1985) which aims



Fig 1 **Google Earth image from 2024 of shore armouring (53 x 8 m) on residential property at Malignant Cove (Antigonish County; 45°47.10'N, 62°05 50'W); armouring in place since at least 2014. Note increased bank erosion of shoreline to the left of the armouring segment where shore erosion has removed ca. 20 m with no apparent change between July 2023 and 2024 images.**



Fig 2 **Google Earth image portion of continuous shoreline armoring of about 250 m at Matheson Cove (45°52.35'N, 63°38.16); this is part of a 600 m long continuous armouring segment. Portion between yellow arrows built since 2019 with the remainder in place since at least 2012.**

to protect fish and fish habitat. Walls are to be placed above the high tide mark and not impact the biology of the shore. The Nova Scotia Beaches Act (1989), protects beaches and associated sand dune systems.

In this paper, we map shoreline armouring on the marine and brackish shores of Nova Scotia facing the Gulf of St. Lawrence and selected estuaries. Case studies of several sites are used to demonstrate impacts on biological communities including sand dunes and salt marshes.

METHODS

Free Google Earth Pro software was used to identify and measure armouring along the shores of the Northumberland Strait and selected estuaries of mainland Nova Scotia facing the Gulf of St. Lawrence (Fig 3). While ground proofing was conducted at many locations, it is possible

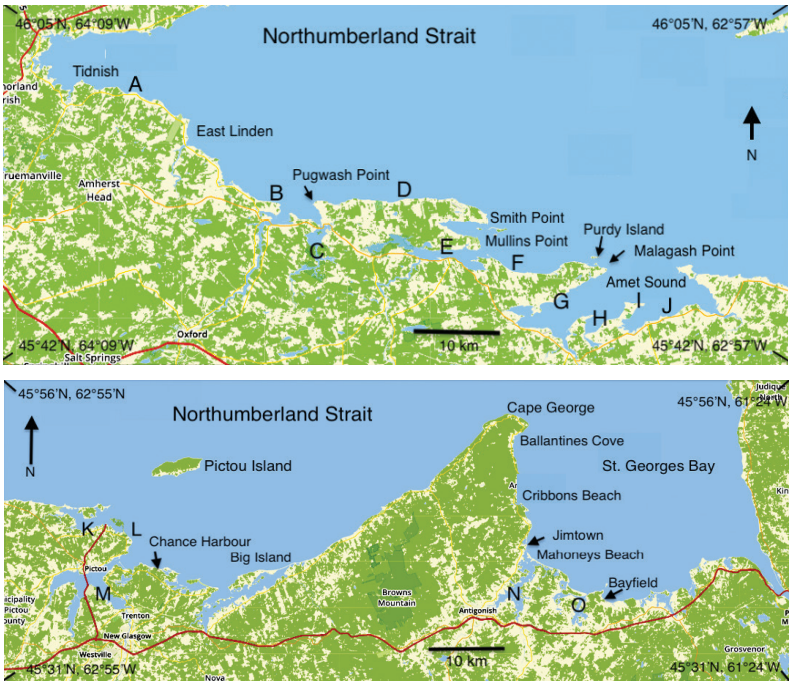


Fig 3 **The North Shore of Nova Scotia indicating western (upper panel) and eastern (lower panel) portions of the Northumberland Strait from the border of New Brunswick (Tidnish) to St. Georges Bay indicating geographic features mentioned in the text and sites A-J where armouring was quantified over transects ca. 4-50 km; see Tables 1-2 for locations and site details.**

that some armouring was missed because of poor Google Earth (GE) images and it is possible that some natural rock formations were mistaken for armour walls. Collapsed CDMs, such as those described by Finck (2007a) from the Amherst Shore would be difficult to resolve with GE. Recent ground surveys showed extensions of CDMs added even after the most recent GE imagery. At the western end of Chance Harbour (45°40.601'N, 62°35.035'W), and the tombolo associated with Big Island (45°41.05'N, 62°20.44'W), rock walls were built and then covered with sand, likely through wave action. To the extent that this is more widespread, it would not have been detected in the GE analysis. Regardless, even low-profile walls with a single row of armour stones, such as at the tombolo at Mitchells Island, can be conspicuous in GE (Figs 4-5). Thus, while some CDMs might have been overlooked, we consider that we have captured the primary extent of shore armouring in the region.

In an initial GE survey, spot samples (254 samples) every 0.5' minutes of longitude (=650 m intervals) from Tidnish to Cape George identified 58 occurrences (22.8% of total) These were plotted in groups of 20 (i.e., 10' of longitude) to show changing frequency of armouring from west to east. We then used GE 'Historical Imagery' under the pulldown menu 'View' to visualize changes in armouring with GE images. This was informative back to ca. 2010 and facilitated a historical perspective for some shores where multiple images were available. This helped overcome constraints of poor lighting, cloud cover, and poor image quality.

We followed the initial overview with a more detailed mapping of 15 selected shores with conspicuous armouring (Tables 1-2). These shores were considered in three categories: Type 1, open coast; Type 2 semi-enclosed bays and harbours, and Type 3, estuaries with well-defined barrier beaches. In GE, the 'Ruler' tool with its 'Path' function was used to measure the length of individual CDMs and the gaps between them. This facilitated quantifying the length frequency distribution of the CDM.

The mapping described above was followed by ground proofing at selected sites to confirm the identification of the CDMs or undertaken as part of field work associated with salt marsh and sand dune ecology beginning in 2012 and 2022 by DG and AT, respectively.

RESULTS

Shore armouring

The Coastal Defense Mechanisms (CDMs, or armouring) consisted mostly of large boulders placed against the shoreline bank, walls up to five metres high, or rows of stacked boulders placed directly on the upper beach surface (Figs 1-2, 4-5). In some cases, wooden pilings were used alone or as supplements to rock walls. Some rock walls had vertical pieces of lumber attached (Fig 6). Finck (2007a) provided an excellent account of the variety of CDMs and their durability used in the region. Many CDMs were within the intertidal zone, and



Fig 4 **Rock wall on beach at margin of sand dune vegetation at Mitchells Island (45°53.59'N, 63°47.73'W) looking northwest along the beach to the island. (Photo DG, June 2025).**



Fig 5 **Google Earth image (2023) of road across dune to Mitchells Island with row or armour stones on beach and portion of salt marsh on opposite side of road.**

Table 1 **Sites used for analysis of coastal armouring on the North Shore of mainland Nova Scotia; sites listed from west to east. Shores were considered as: Type 1 – open coast of Northumberland Strait; Type 2 – semi-enclosed bays and inlets; Type 3 – enclosed estuaries typically with barrier beaches. See Fig 3 for general location of sites.**

Site	Shore type	Start of transect	End of transect
A Tidnish to East Linden	1	45°59.67'N, 64°02.30'W	45°54.00'N, 63°48.82'W
B Heather Beach to Toney Creek	1-2	45°52.50'N, 63°45.01'W	45°51.79'N, 63°44.76'W
C Pugwash Harbour	3	Entire estuary	
D Pugwash Point to Smith Point	1	45°52.28'N, 63°40.74'W	45°51.03'N, 63°24.80'W
E Wallace Harbour bridge to Mullins Point	2	45°49.36'N, 63°29.01'W	45°50.04'N, 63°25.68'W
F Cambra sands to Purdy Island	1	45°48.87'N, 63°24.42'W	45°48.36'N, 63°14.85'W
Amet Sound:			
G Emerys Island to Malagash Point	2	45°45.90'N, 63°19.95'W	45°47.17'N, 63°13.98'W
H Brule Shore	2	45°45.04'N, 63°15.90'W	45°45.04'N, 63°12.93'W
I Brule Point	2	45°45.04'N, 63°12.93'W	45°44.90'N, 63°12.93'W
J Semple Creek to River John	2	45°44.22'N, 63°11.58'W	45°45.10'N, 63°03.52'W
Caribou Harbour:			
K Three Brooks to ferry terminal	3	45°43.99'N, 63°44.73'W	45°44.21'N, 62°41.43'W
L Caribou and Munroe's Island Park east towards Pictou	1	45°43.45'N, 62°39.00'N	45°41.70'N, 62°39.61'W
Pictou Harbour:			
M Abercrombie Point to Trenton Connector	3	45°39.41'N, 62°43.00'W	45°37.42', 62°39.09'N
N Antigonish Harbour	3	Entire estuary	
O Pomquet Harbour	3	Entire estuary	

at high tide the water lapped on rock walls or the bases of timbers with populations of seaweed (mostly *Fucus vesiculosus*, and filamentous and ulvoid green algae). Barnacles were often present. During spring tides and especially during storms, wave action impacts the CDMs. CDMs occasionally comprised gabions that were filled with stones, although these could not be resolved using GE.

The 254 point samples for presence of armouring between Tidnish and Cape George Lighthouse (164 km) gave 58 occurrences with armouring (22.8%), with the remaining sites being sandy beaches, gravel shores,



Fig 6 **Three-metre tall rock wall supplemented with wooden beams in high intertidal zone of Amherst Shore. (photo DG, June 2025)**

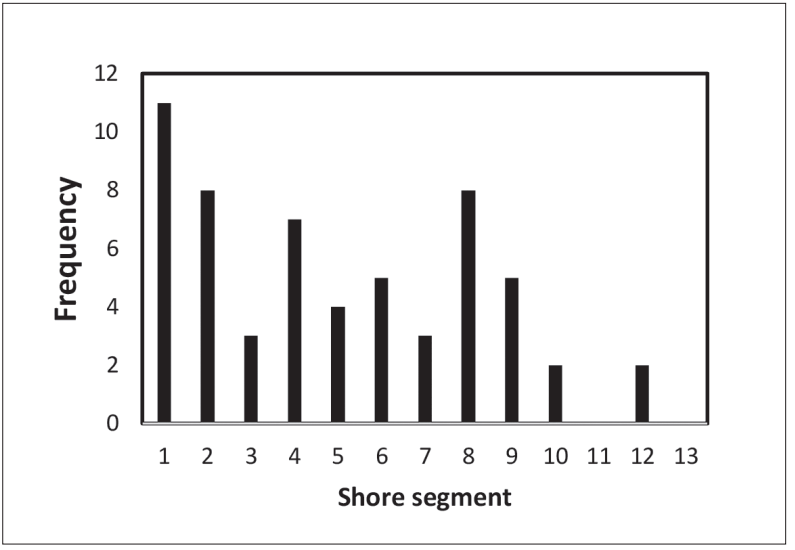


Fig 7 **Frequency of armouring in successive point samples of 20, for each 10' of longitude measured every 0.5' from Tignish (segment 1; 45°59,74, 64°02.50'W) to Cape George (segment 13, 45°53.13'N, 61°64.50'W), Nova Scotia. Segment 8 includes the end of Caribou Island. Note: three of the armouring points in segment 9 are protecting the road to Big Island and not associated with housing.**

Table 2 **Shore armouring at selected sites on North Shore of Nova Scotia including sites directly exposed to Northumberland Strait and in bays and estuaries; data derived from Google Earth images using 'historical imagery' and 'path' tool. See Fig 3 for general location of sites.**

Site	Number of armour walls	Summed length of armouring (m)	Shore length (km)	Shore armouring (%)
A Tidnish to East Linden	44	10350	25.0	40%
B Heather Beach to Toney Creek	6	2676	3.7	74%
C Pugwash Harbour	6	1722	35.5	8% (5%*)
D Pugwash Point to Smith Point	30	6113	24.9	25%
E Wallace Harbour Bridge to Mullins Point	9	2063	6.1	34%
F Cambra sands to Purdy Island	14	1872	13.3	12.5%
Amet Sound:				
G Emerys Island to Malagash Point	29	4064	12.4	33%
H Brule Shore	9	2230	4.6	49%
I Brule Point	9	2744	9.1	30%
J Semple Creek to River John	19	4917	14.1	35%
Caribou Harbour:				
K Three Brooks to ferry terminal	7	718	5.1	14%
L Caribou and Munroe's Island Park east towards Pictou	9	2211	4.6	48%
Pictou Harbour:				
M Abercrombie Point to Trenton Connector Bridge	14	1665	9.1	18%
N Antigonish Harbour	10	1592	50	3%
O Pomquet Harbour	1	1100	40	3%

*Excluding the 900-m causeway across the estuary to the salt mine

steep banks, and salt marshes. Armouring was found to be more frequent at the western end of the study area with 19/40 samples (47.5%) scoring positive than it was found at the eastern end where 2/54 samples were positive (3.7%, Fig 7).

The second method examined 15 sections of shoreline (Table 2; Fig 3, A-O) with lengths ranging from about 5 to 50 km. These were selected based on the occurrence of conspicuous CDMs visualized in GE.

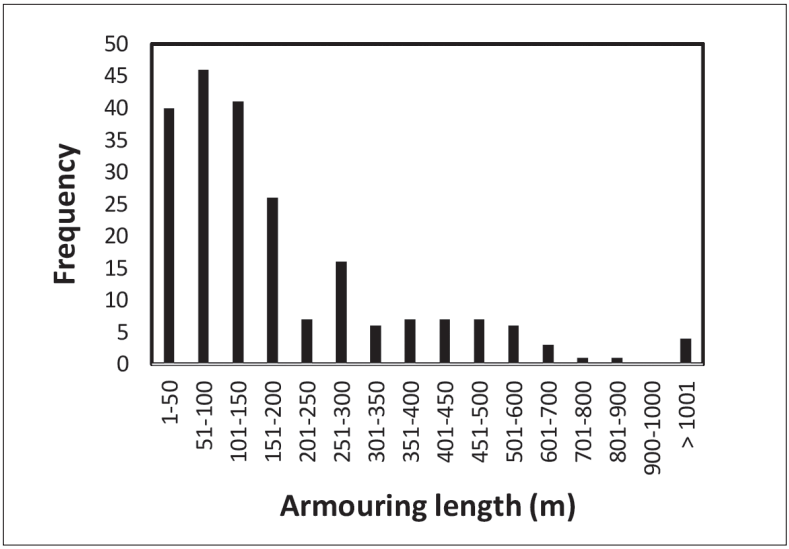


Fig 8 Size-frequency distribution of 218 armour segments from areas listed in Table 1.

The first shore segment examined a portion of the western end of the transect described in the previous paragraph whereas the others were independent lengths of armouring on selected outer shores (Type 1), partially enclosed bays and harbours (Type 2), and estuaries (Type 3). The 218 individual emplacements combined for 37.9 km of armouring and ranged from 19 to 1936 m long (216±245 m, mean±s; 130 m, median; Fig 7). The most frequent armour wall length category was 51-100 m (36 occurrences). These walls were for one or adjoining properties, whereas the longer runs of CDMs included many properties (Fig 2) with the longest continuous walls being for roads and golf courses. The 15 selected shorelines and estuaries (Fig 3, A-O) provided a means to compare armouring on different shore types (Table 1). Both Type 1 and Type 2 shores had extensive CDMs (means of 36% to 40% for sample shorelines) that were not statistically different (Student's t-test, $P>0.05$). These values were at least 60% higher than the method based on the systematic sampling of longitude. This is not surprising, as Type 1 and 2 shores were mostly selected based on occurrence of CDMs, thus making these non-random samples. Type 3 shores had dramatically reduced cover of CDMs, with generally <5% shore cover. Despite the difference in methods, this is dramatically less than the systematic samples of the outer shores of the Northumberland Strait.

This was consistent with other Type 3 sites, e.g., Merigomish and Tracadie Harbours, where formal measurements were not conducted. In addition, in the Type 3 sites much of the armouring was associated with protection of roads and non-residential structures, e.g., the causeway across the harbour to the salt mine. Types 1 and 2 shores were often densely packed with seasonal dwellings that were constructed close to the shore for access to the beach. Small lots also precluded moving buildings away from the shore. Consequently, sea-level rise required construction of CDMs to preserve the property. Buildings on Type 3 shores are typically associated with permanent residences or barns that were constructed away from the water, with landowners more accepting of natural erosional forces.

Case Study: Salt marsh at Trenholm Beach Road, Northport

The shoreline north of Pipes Beach has been extensively armoured to protect the numerous summer residences on the shore (Figs 9-11). There is a small salt marsh facing the open Northumberland Strait (45°56.92'N, 63°52.07'W). Construction of a new dwelling resulted in the recent extension of an existing rock wall. Unfortunately, the extension wall was built across part of the remnant salt marsh and below the high tide mark (Fig 10), causing partial destruction of the salt marsh. In general, the impact of sea-level rise tends to have greater erosional impact on the lower margins of marshes; however, this marsh is being directly and indirectly damaged by the rock wall. This has resulted in a conspicuous 'dead zone' at the upper side of the marsh adjacent to the rock wall where the peat is still intact but there are no living, i.e., emergent shoots of *Sporobolus alterniflorus* (Cord grass, Fig 11). This marsh loss will likely continue along the top of the marsh, eliminating the Cord grass and reducing the area of marsh peat. By limiting exchange from the previous shoreline, sediment transfer is being cut off. While this marsh remnant has been under pressure from sea-level rise, the additional problem of the CDM is hastening its eradication.

Table 3 Summary of armouring amount based on exposure: Type 1, facing the exposed Northumberland Strait; Type 2, in semi-enclosed bays and harbours; Type 3, estuaries with barrier beaches; n = 5.

	Shore type		
	Type 1	Type 2	Type 3
Mean ± s	40 ± 23%	36 ± 8%	9 ± 7%



Fig 9 **Google Earth image from 2019 of 6-m wide rock wall on top of remnant salt marsh at Northport (45°56.91'N, 63°52.08'W).**



Fig 10 **Remnant salt marsh with monoculture of *Sporobolus alterniflorus* at Northport. Note: the same house is visible Fig 9. (photo DG, June 2025)**

Case Study: Big Island Beach, Merigomish, Pictou County

Background: Big Island Beach is a barrier beach tombolo that connects the mainland near Merigomish to Big Island. Big Island Road provides access to the island along the barrier and access to the beach for recreation (Fig 12-13). It is the sole road to the island and is protected by extensive rock armouring at least 2.6 km long in a preservation effort



Fig 11 Upper limit of salt marsh near rock wall at Northport with 'dead' zone, i.e. intact peat mass with no emergent salt marsh flowering plants near rock wall; several rocks have populations of *Fucus vesiculosus*, barnacles and various ulvoid algae. (photo DG, June 2025)

against sea-level rise and storm activity. The road and its armouring have been in place prior to at least the 1960s.

Current status: The rock armouring is alongside the road and follows its contour. As such, at its western extent where the road veers inland, the rock wall is above the high-water mark and back from the seaward limit of the sand dune plant community (mostly *Ammophila beviligulata,* American Beach Grass; *Lathyrus japonicus,* Beach Pea; *Morella pensylvanica,* Bayberry). However, east of this, the seaward position of the road causes a substantial proportion of the rock armouring to be in contact with waves at high tide and during storm surges. There is little dune remaining seaward of the rock wall here and scouring is evident (Fig 12-13). This process is beginning to occur along the intact dune at the western end of the armouring. Sea-level rise is bringing the armouring into contact with the waves causing scouring of the adjacent dune (Fig 12). Big Island demonstrates a fundamental issue with utilizing rock armouring, where armouring is no longer above the high tide mark with rising sea levels. This causes a significant loss of habit, particularly of beach zones.

Future concerns: The forced static position of the barrier beach created by the road and armouring will cause waves to reach higher on the beach with rising sea levels. The waves will come into greater



Fig 12 Rock wall at Big Island covering previous sand dune with the sand dune beach community eroded away. (Photo AT, May 2024)



Fig 13 Portion of rock wall at Big Island. (Photo AT, July 2025.)

contact with the rock wall, increasing loss of the seaward dune and causing further habitat loss. The probability of waves overtopping the road and barrier beach will also increase with sea-level rise, risking further damage to the beach system. Long term projection would be the barrier breaking up or drowning as a direct result of the armouring.

Case study: Mahoneys Beach, Antigonish County

Background: Shoreline changes at Mahoneys Beach in Antigonish County have been attributed to longstanding armouring (mostly prior to 1990 but with annual renewal following winter storms) on the

adjacent shore and continuing northward for about 700 m to Jimtown. The armouring protects residences at Jimtown and road access to residents at Mahoneys Beach (Fig 14). The armouring consists of extensive rock walls and several groins. The armouring ends at the beach access parking lot. In December 2004, a storm formed a new channel into Antigonish Harbour that has remained to the time of this study. The channel prevented both foot and vehicular traffic onto the >1.5 km extent of the barrier beach. Utting and Gallagher (2009) reported on the coastal geomorphology of this part of St. Georges Bay (Jimtown to Pomquet) and described how the opening of the new channel into Antigonish Harbour could be attributed to the armouring on this shoreline. The groins and the CDM restricted sediment accumulation from a longshore current from the north. The accumulated sand deficit resulted in sand removal from the public beach that was deposited into the newly formed sand bar on the interior side of the new opening into the harbour. More recent shoreline changes are described below.

Current status: Since 2012, the shoreline of Mahoneys Beach and changes to the vegetation of the barrier-beach system to the east of the new channel (here referred to as Mahoneys Island) have been monitored. The vegetation has dramatically changed on the remnant dune system adjacent to the parking lot. Only a small fringe of American Beach Grass (*Ammophila breviligulata*) remains along the seaward edge, with scattered clumps of herbaceous dune species interspersed with about 50% bare sand. Over the previous dune surface are numerous small



Fig 14 Google Earth image of Mahoneys Beach (2019) with three groin remnants and gravelized beach; opening into harbour formed in December 2004.

boulders deposited by wave action. The invasive species Crown vetch (*Coronilla varia*) has become a dominant species as described previously for Mahoneys Island (Flynn *et al.* 2013). The beach has become relatively more gravel-rich as finer material has been eroded leaving an extensive boulder field. Many boulders have been wave-tossed onto the remnant sand dune.

There has been extensive retreat of the vegetation on Mahoneys Island where a third of the dune area has been lost since an initial survey by DG in 2012 (Garbary *et al.* 2025; Fig 10). While Hurricane Fiona (September 24, 2022, e.g., Straub 2024) may have enhanced background rates of erosion, annual changes to the system can be attributed to loss of sand from the dune margins and increasing rates of sea-level rise. The disturbance is also associated with the establishment of *Coronilla varia* (Crown vetch) that has become a dominant plant in areas previously dominated by *Ammophila* and *Lathyrus* (Flynn *et al.* 2013). *Picea mariana* (Black spruce) and *Morella* often occur at the dune margin with roots often exposed on the scarped edges. Extensive overwash has pushed sand well into the dune interior and killed or stunted the Black spruce. A 250-m section at the western end of the island has only scattered weedy vegetation; what was previously a dune 1-2 m above the beach during 1980s is now barely elevated above the high tide mark.

Rest of St. Georges Bay to the Canso Causeway

There is little armouring on the western side of St. Georges Bay other than the rock walls protecting harbours (i.e., Ballantynes Cove and Cribbons Harbour, on the west side; Bayfield Harbour on the south; and major transportation infrastructure (e.g., around the Canso Causeway).

There is a 190-m armouring at Cribbons Beach (45°45.967'N, 61°54.503), a 700-m armouring from Jimtown to Mahoneys Beach described above, and scattered smaller walls associated mostly with residential properties within estuaries.

Erosion in Archibald's Cove in Antigonish Harbour (Fig 15) has been observed since the early 2000s (Garbary and Miller unpubl.). In 2005, an *S. alterniflorus* marsh was present up to 10 m wide with the peat about 50 cm thick. Marsh loss was occurring at 0.5-1.0 m y^{-1}. There was a gap of 19 years of observation, but by 2024 the marsh and its peat had eroded away to the tree line (Garbary unpubl.) with many trees (mostly Poplar, Red maple and Spruce) having collapsed onto the shore or with exposed roots from bank undercutting. Some trees along the shoreline were observed to be leaning into the forest, likely



Fig 15 Google Earth Image (2024) of seashore in Antigonish Harbour; see text for discussion.

resulting from Hurricane Fiona that caused extensive windfall in the surrounding area. The sediment surrounding the exposed upper surface of rocks was extremely soft with a muddy consistency where, when walking, one would often sink ankle deep. On an adjacent property where extensive clearing had been done and a rock wall placed in the upper intertidal zone on the bank in 2019, the sediment was firmer, remnant peat and Cord grass remained, and the CDM provided habitat for periwinkles and filamentous green algae. During spring tides the interstices of the rock wall would provide habitat refuge for small fish. While the intertidal zones in the presence or absence of the CDM had healthy populations of oysters and mud snails, these species were more prominent on the shoreline with the CDM.

DISCUSSION

In a meta-analysis, Sauvé *et al.* (2023) provided a global perspective of the variety of coastal defense measures (CDMs) and their impacts. While the authors were based in Canada, none of the 355 case studies from 301 publications were Canadian examples because they did not meet their selection criteria. This suggests that the relevant observations on CDMs have not been carried out in Canada. Our study meets all the Sauvé *et al.* (2023) criteria including: (1) observations made by the authors, (2) the observations include changes to the coastal system relative to a baseline condition, and (3) concludes that the changes

were caused by the CDM. Accordingly, our assessment of armouring in northern Nova Scotia provides an important study of the extent and impacts of CDMs in eastern Canada.

The north shore of Nova Scotia along with many of its bays and estuaries (Table 1) is now extensively armoured with rock walls placed at the top of the shore typically attached to the property of the landowner (Finck 2007a, b). The largest continuous CDM is associated with a causeway and sand dune-barrier beach system at Big Island protecting the only road to the island. This armouring and road caused major damage to the sand dune system and they have not been effective in preventing blowouts and subsequent damage to the road. Indeed, the armouring has required major repairs seemingly on an annual basis. Dugan *et al.* (2008) showed major reductions in the diversity and abundance of birds on armoured versus unarmoured sections of shoreline in southern California. In the Maritime Provinces, the upper beach of sand dunes is the habitat for the endangered Piping Plover (*Charadrius melodus*; Environment Canada 2012); rock walls in this habitat without restoration of the foreshore, e.g., Mitchells Island and Big Island, would limit habitat availability.

There are three primary plant communities associated with marine shorelines of the Northumberland Strait: salt marshes, sand dunes and seaweeds. These communities would fall under the jurisdiction of the Fisheries Act and the Beaches Act because of their importance as fish habitat, their biodiversity, and importance as communal recreational resources. The establishment of seawalls and the armouring of shorelines are rarely placed so that they directly cover salt marsh habitat although two exceptions have been observed: (1) near Pipes Beach and (2) in Antigonish Harbour. In both cases, the marsh was a remnant of a larger area that had been in decline. It is unclear whether the demise of the marsh remnants (Fig 10, 15) was hastened by shore armouring. Regardless, removing these walls would lead to extensive habitat damage from heavy equipment and shore siltation.

The marsh remnants on shores facing the Northumberland Strait are being lost because of sea-level rise, consistent with observations from New England (Donnelly and Bertness 2001). These patches of dead peat suggest recent mortality that can be related to shore armouring. Regardless of the extent to which this has occurred, it is impacting habitat. Shoreline armouring disrupts the land-sea ecotone and the exchange of materials between them (Heerhartz 2013, Heerhartz *et al.*

2013). Small-scale armouring associated with residential development – the primary form of CDMs in the Northumberland Strait – may impact salt marsh plant diversity where species diversity can be restricted to a single species, *Sporobolus alterniflorus* (Garbary unpubl.). This feature of the remnant marshes was also observed in coastal Georgia, USA (Gehman *et al.* 2018).

While the predominant strategy to adapt to increased coastal erosion due to sea-level rise in northern Nova Scotia has been seashore armouring, little effort has gone into mitigation that could limit the need for armouring. Potential mitigation measures for Mahoneys Beach might include the removal of the six deteriorated groins that are currently restricting sand deposition and building more effective armouring systems to prevent road washouts. Gracia *et al.* (2018) suggested that establishment and restoration of natural ecosystems, e.g., salt marsh and seagrass vegetation, dampens wave action and increases sedimentation, thus, limiting the erosional forces of sea-level rise. Considerable effort has gone into salt marsh restoration in the upper Bay of Fundy (e.g., Bowron *et al.* 2012, Ollerhead *et al.* 2020, Rabinowitz *et al.* 2023); however, this has not been explored in northern Nova Scotia where historical dykes are not relevant to the issue of seashore armouring. A starting point might be the remnant patches of marshes on the Northumberland Strait at Tidnish and Northport where interventions might reverse the current marsh loss even with extensive shore armouring. There is some capacity for the recolonization of increasingly gravel-rich shores by Cord grass following peat loss in estuaries (Garbary unpubl.); however, the long-term viability of these populations needs to be studied.

Property owners have always been able to build armouring structures when these were installed above the high-water mark. Sea-level rise and potential erosion below the armouring structures can subsequently lower their relative position and result in these structures no longer having this setback. Thus, during high tides the water level can be above the base of the armouring structure. This may, in fact, provide a positive impact on marine life by increasing habitat complexity. The rock surfaces can provide substrate for marine algae and barnacles, and the spaces between rocks refuge for small or juvenile fish and shellfish.

Another critical aspect of shore armouring is the impact that a property owner is having on their neighbour or adjacent public shorelines (reviews by Griggs 2005, Sanitwon-Na-Ayutthaya *et al.* 2023).



Fig 16 Google Earth image from 2024 with armoured shoreline (ca. 50 m) in Amet Sound (45°45.26'N, 63°7.72'W) with differential shore erosion on either side of armouring wall. Vegetation retreat on left side was 14 m since 2011.

Once a small stretch of wall is installed, it can impact the adjacent properties by increasing the erosion (Fig 1, 16, 17). Whereas the neighbours might have been accepting of a limited rate of shore retreat, the presence of the CDM will automatically have a negative impact on their property value because of the increasing erosion rate. Surely, this is unethical as it imposes a major expense to expand the wall and limit property loss. Such a situation requires legislation to clarify the rights of property owners to both install shoreline armouring and to be protected from neighbours. In 2024, the Nova Scotia government did not proclaim the passed provincial Coastal Protection Act (Nova Scotia 2019) which was to include regulations that might have remedied this deficiency. Current government policy downloads the responsibility for managing coastlines onto municipalities who can impose local regulations regarding building and setbacks. Sauvé *et al.* (2020, 2022, 2023) proposed approaches to decision making for management of coastal defenses and placed this in a holistic socio-ecologic framework involving stakeholders in participatory decision-making that recognizes local context.

The fate of the barrier beach for Antigonish Harbour, i.e., Mahoneys Island, is an environmental tragedy. Having lost over 30% of the vegetated dune surface in 12 years (2012-2024) with extensive overwash



Fig 17 Google Earth image from 2024 indicating CDM consisting of rock walls at both ends of public beach beside Caribou Island Road (45°45.64'N, 62°44.41'W). Red lines indicate margin of dune vegetation in 2004 and indicate beach retreat of about 10 m on neighbouring property and on public beach.

and dieback of the remaining vegetation at the north end of the island, it has shown greater deterioration than any of the more than 30 beach systems studied in northern Nova Scotia over the same period (Garbary *et al.* 2025, Garbary unpubl.). While Hurricane Fiona also inflicted major erosion on this system, the primary damage predated this storm. Implemented over many years and clearly permitted (or ignored) by authorities, the armouring at Mahoney's Beach has proved both partly ineffective (as shown by the almost annual renewals) and has led to the deterioration of public amenities and ecosystem function. The questions become: (1) Who or what government agencies are responsible for this ongoing deterioration on Mahoneys Beach and Island? and (2) Should those same agencies be responsible for mitigation and restoration?

The questions posed in the previous paragraph were discussed in a general sense in an American context of the 'Public Trust Doctrine' (Liss 2016). Liss concluded that the State is required to protect trust resources, i.e., the natural environment. This concept is less well developed in a Canadian context (Ahmed 2024), although its application could develop into a robust approach for initiating government action regarding mitigation of climate change of which sea-level rise is a key component. Richardson and Wells (2024) emphasized the need for coordinated coastal management in Nova Scotia and the need for the Coastal Protection Act; their discussion is an elaboration of the Public Trust Doctrine. Clancy and Levesque (2025) discussed the limitations of environmental governance of the Gulf of St. Lawrence and concluded (p. 124) that "the pursuit of coastal management remains

in large part aspirational today." To move forward, we need a deeper understanding not only of the ecological impacts of armouring, but also of the economic and social returns that armouring provides. Here we have shown that around 20% of a significant portion of Nova Scotian shores on the Northumberland Strait have been armoured, with many smaller stretches having 40%, or more, with armour walls. Climate change and sea-level rise require both risk assessment (Anonymous 2025) and better management of where and how armouring is to occur.

Acknowledgements We thank landowners who facilitated access to shorelines and for helpful discussion regarding the history of armouring at various sites. This work was funded in part by grants to DJG by NSERC and DFO.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 471-484

INVASIVE *FUCUS SERRATUS* (PHAEOPHYCEAE) REPLACES SHALLOW WATER KELP COMMUNITY IN SOUTHWESTERN NOVA SCOTIA

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ABSTRACT

Along the Atlantic coast of Nova Scotia, recent observations in 2020-2021 of the intertidal zone showed that the European native fucoid *Fucus serratus* was becoming more widely distributed, both geographically and ecologically. Here, we extended these observations to the shallow subtidal zone (to about 5 m below chart datum) in southwestern Nova Scotia. We used semi-quantitative and qualitative sampling via snorkeling at selected mainland and offshore island sites, observed using both transects (50 m) and spot sampling. At all sites, the expected populations of kelp species (i.e., *Laminaria digitata*, *Saccharina latissima,* and *Alaria esculenta*) were absent to rare, and extensive populations of *F. serratus* were present with > 50% cover that formed the dominant canopy species. The decline in kelp species mirrors previous accounts of kelp population collapse in St. Margaret's Bay and Lunenburg Bay in recent decades but differs in that the canopy species is *Fucus serratus* rather than red algal turfs. While ocean warming may be playing a role in regional kelp decline, significant warming did not occur in Nova Scotia until the late 1990s. We suggest that the commercial harvesting of *Chondrus crispus* by the 1970s played a key role in the replacement of shallow water kelp beds by *Fucus serratus*.

Keywords: Climate change, *Fucus serratus*, irish moss, kelp, Nova Scotia, seaweed harvesting

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INTRODUCTION

Kelp forests are declining globally (Krumhansl *et al.* 2016) with declines attributed to a variety of human induced factors including climate change and overharvesting. This decline has been noted along the Atlantic coast of Nova Scotia where an ocean warming hotspot has been implicated in the changes in community structure (Hobday and Pecl 2015, Filbee-Dexter *et al.* 2016). Here we show declines of kelp species in the southwestern corner of Nova Scotia, an area with a long history of harvesting of both *Chondrus crispus* Stackhouse (Irish moss) and *Ascophyllum nodosum* (Linnaeus) LeJolis (rockweed) (MacFarlane 1952, Pringle and Semple 1980, Vandermeulen 2013). We suggest that the overharvesting of Irish moss rather than ocean warming provided disturbance regime that facilitated kelp decline and its replacement as a canopy species by invasive *Fucus serratus* Linnaeus.

FUCOIDS AND KELP IN SOUTHWESTERN NOVA SCOTIA

Fucus serratus is native to western Europe where it is found on rocky shores from Spain to northern Norway and the White Sea (Guiry and Guiry 2026). In the British Isles and Ireland, it is a common component of intertidal shores where it can be a dominant species (e.g. Lewis 1964). The species was introduced in ship ballast to Nova Scotia in the mid-1800s from western Ireland and Scotland (Brawley *et al.* 2006). It subsequently colonized subtidal habitats around Cape Breton Island and has become widely distributed in eastern Canada with extensive populations in the southern Gulf of St. Lawrence of Nova Scotia, New Brunswick and Prince Edward Island (Johnson *et al.* 2012, Garbary *et al.* 2021). A population of *F. serratus* of unknown provenance occurs in the southwestern part of Nova Scotia in Lobster Bay. MacFarlane (1952) first noted that it occurred in "considerable quantities" in the Tusket Islands (Fig 1). Surveys and reviews in the 1970s by Edelstein *et al.* (1972), Wilson *et al.* (1979), Dale (1982), and Novaczek and McLachlan (1989) indicated a limited distribution on the mainland. Furthermore, in the 1970s a detailed survey of the low intertidal and subtidal locations on both the mainland and islands in Lobster Bay and adjacent Shelburne County showed the standard zonation pattern of a red algal zone dominated by *Chondrus crispus* leading to kelp communities in the adjacent subtidal area (Pringle and Semple 1980).

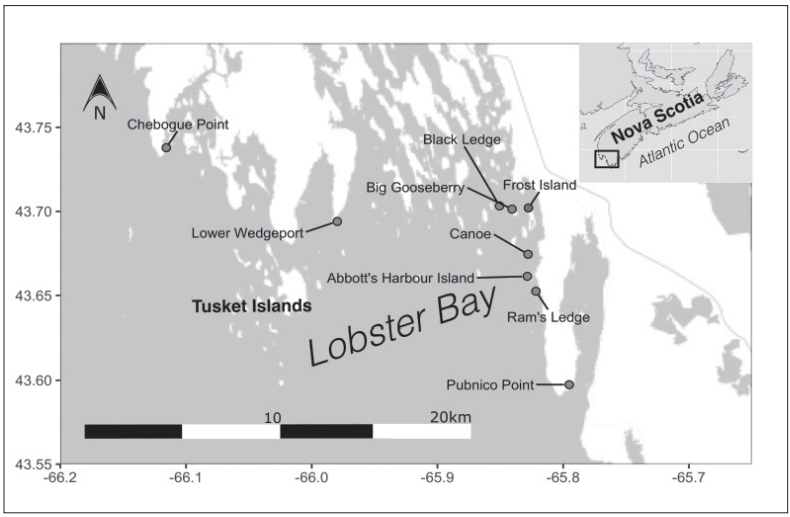


Fig 1 Map of southwestern Nova Scotia indicating sample sites in June 2021. See Table 1 for site coordinates.

A major departure from this pattern was observed by Novaczek and McLachlan (1989) and Garbary *et al.* (2021) in which *F. serratus* had become a dominant, canopy species in the low intertidal zone (Lobster Bay and Lunenburg Bay) as well as subtidally (Lunenburg Bay). Here we report on the replacement of low intertidal and shallow subtidal kelp communities in southwestern Nova Scotia by *F. serratus*.

MacFarlane (1952) surveyed kelp and fucoid algae in southwestern Nova Scotia with a focus on Yarmouth County and immediately adjacent areas in Shelburne and Digby Counties. Kelp species included *Alaria esculenta* (Linnaeus) Greville, *Laminaria digitata* (Hudson) J.V. Lamouroux, *Saccharina latissima* (Linnaeus) C.E. Lane, C. Mayes, Druehl & G.W. Saunders (as *L. longicruris*), *Sacchoriza dermatodea* (Bachelot Pylaie) J. Agardh (as *Phyllaria*), and *Agarum clathratum* Dumortier. Importantly, *Laminaria* and *Saccharina* were described as widespread and abundant on both offshore islands and mainland sites. MacFarlane (1952) described the kelp and fucoid species in this part of the province with the phrase "in all of which the region abounds" with *F. serratus* restricted to the Tusket Islands (Fig 1). Edelstein *et al.* (1972) concluded that *F. serratus* had not spread beyond the Tusket Islands, although soon afterwards a transect at Cheboque Point in 1977 by Novaczek and McLachlan (1989, Fig Site 25 in Appendix 3) that included both the intertidal and shallow subtidal zones indicated both

Laminaria digitata and *S. latissima* (as *L. saccharina*) as common above lower low water spring tide, and these kelp species were shown as abundant. This transect showed a clear zone of *F. serratus* between the lower limit of *A. nodosum* and the low tide mark. Additional sites for *F. serratus* in Lobster Bay were added by Dale (1982) and Johnson *et al.* (2012).

Despite being observed in southwestern Nova Scotia for 70 years, there have been few accounts of the local distribution and ecology of *F. serratus* or the factors accounting for its spread. The absence of critical observations in the area is important because of the ability of *F. serratus* to become a dominant, band-forming and canopy species in habitats of *C. crispus* both in Lobster Bay and 150 km to the northeast in Lunenburg Bay, occupying 20% and 40% of the intertidal zone, respectively (Garbary *et al.* 2021). This apparent change in zonation pattern along the Atlantic coast of Nova Scotia (cf. Stephenson and Stephenson 1954a, b, Novaczek and McLachlan 1989) prompted us to undertake a snorkeling survey of low intertidal and shallow subtidal sites in Lobster Bay June 21-26, 2021 (Fig 1, Table 1).

Elsewhere, human introductions of *F. serratus* have led to the establishment of populations in Iceland and the Faroes (Coyer *et al.*

Table 1 Transect and boat survey sites for *Fucus Serratus* in Lobster Bay via snorkeling in June 2021.

Transect from shore	Coordinates	Comments
Chebogue Point	43°44.28' N; 66°6.92' W	T1: sandy with large boulders; eelgrass at 40 m T2: mainly large cobble T3: boulders, line tangled at 30 m
Lower Wedgeport	43°41.63' N; 65°58.74' W	T1: boulder field, *Codium* at 10m and 15m T2: boulder field
Pubnico Point	43°35.67' N; 65°47.91' W	T1: sandy with cobble and boulders T2: sandy with cobble and boulders T3: sandy with cobble and boulders
Snorkel surveys from boat		
Ram's Ledge (Chemin du Rocher)	43°39.15' N; 65°49.30' W	Moderately exposed shore
Abbott's Harbour Island	43°39.68' N; 65°49.71'W	Moderately exposed island
Canoe Island	43°40.47' N; 65°49.66'W	More protected island
Frost Island	43°42.12' N; 65°49.66' W	Well protected nearshore island
Black Ledge	43°42.20' N; 65°51.04' W	A tidal channel reef
Big Gooseberry Island	43°42.08' N; 65° 50.44'W	Moderately protected

2006). The report by Hooker (1811, cited by Guiry and Guiry 2027) shows that the introduction to Iceland preceded that to eastern Canada (Brawley *et al*. 2009). The species has established canopy-forming populations in the low intertidal zone along at least 100 km of shoreline in the southeastern corner of the island (Ingólfsson 2008) with limited populations on the south coast (Munda 2011). Despite the longer residence in Iceland, the ecological and geographic distribution is more limited than in eastern Canada. More recent surveys are required to determine if climate change and seaweed harvesting have impacted the distribution of *F. serratus* in Iceland.

SURVEY OF LOBSTER BAY

At three mainland sites (Chebogue Point, Lower Wedgeport and Pubnico Point), two (Lower Wedgeport) or three (other sites) 50-55 m transects were surveyed perpendicular to the shore beginning at the low water mark (about 0.7 to 1.0 m above chart datum) starting at the lower limit of a distinct zone of *A. nodosum*. Cover of *F. serratus* was recorded at 5-m intervals. The transects were 50 m apart at each site. The same observer (HV) estimated the abundance of *F. serratus* on a three-point scale (20% cover; 20-60% cover, and 60-100% cover). Maximum depth of the transects was about 2 m below chart datum. At all sites, solid substrata (boulders and large cobbles) along the transect lines had an abundance of *F. serratus* and no kelp (Table 2). Another invasive species, the green alga *Codium fragile* (Suringar) Hariot, was observed in one transect at Lower Wedgeport (Table 2). The record for *Codium* is the first for Lobster Bay and represents a range extension of about 150 km from the previously published location at Puddingpan Island (Watanabe *et al.* 2010). The low intertidal and subtidal habitats at our transect sites would have been dominated by *L. digitata* and *S. latissima* in the 1970s. The transect at Chebogue Point from 1977 by Novaczek and McLachlan (1989) had *F. serratus* forming a zone below *A. nodosum* and stopping above chart datum, and with *L. digitata* overlapping with *F. serratus* and exposed at the lowest of the spring tides. These changes in canopy dominants in the subtidal zone of Lobster Bay also were not apparent in the detailed surveys done in the mid-1970s by Haggerty and Hellenbrand (1976) and Pringle and Semple (1980).

Table 2 **Snorkel surveys indicating cover of *Fucus serratus* from 22-26 June 2021 using a transect line perpendicular to the water edge beginning at low water. Multiple transects at each site were separated by 50 m; see Table 1 for habitat details. Abbreviations: CP, Chebogue Point; WP, Lower Wedgeport; PP, Pubnico Point. Key to cover of *Fucus serratus*: 0, absent; +, about 20%; ++, 20–60%; +++, 60-100%; ND, no data.**

Location	Position (m)											
	0	5	10	15	20	25	30	35	40	45	50	55
CP1	+	+	++	++	++	++	++	++	++	+	++	0
CP2	++	++	++	++	++	++	++	++	++	++	++	0
CP3	+++	++	++	++	+++	++	+++	ND	ND	ND	ND	ND
WP1	++	++	++	+++	+++	++	+	+++	+	+++	++	++
WP2	+	+	+	+++	+++	+	++	+	+	+	+	+
PP1	0	+	+++	++	0	0	0	0	0	0	0	+
PP2	+	+++	+++	+++	+++	+++	+++	++	+	+	+	0

Offshore snorkeling surveys in shallow water at seven locations in Lobster Bay (Fig 1, Table 1) gave a similar result to the transects described above. These surveys were carried out when the tide covered the lower portion of the shore and *A. nodosum* was the canopy dominant. This gave way to *A. nodosum* with epiphytic *F. serratus,* and then to dense beds of *F. serratus* largely devoid of kelp. At about 4–5 m depth, the canopy was dominated by *L. digitata.* At Frost Island and Big Gooseberry Island the substratum changed to sand and gravel with a bed of *Zostera marina*.

HISTORICAL CHANGES TO SEAWEED COMMUNITY

It is unclear when the change in dominant canopy species occurred in Lobster Bay. The Dale (1982) and Novaczek and McLachlan (1989) accounts suggest that these changes were underway in the 1970s when they conducted their transects at Chebogue Point and Pubnico Point (as St. Ann Point). Surveys at numerous sites in Lobster Bay in the mid-1970s reporting depth limits of 30 macroalgal species do not record *F. serratus* (Pringle and Semple 1980). These authors illustrate a small band of *'Fucus'* at around chart datum (their Fig 2) that might refer to *F. serratus* or to *F. distichus* spp. *edentatus* (Bachelot Pylaie) H.T. Powell; the latter occurs at this same tidal height and was reported from Lobster Bay (MacFarlane 1952, Edelstein *et al.* 1972, Wilson *et al.* 1979). With respect to kelp, Pringle and Semple (1980) refer to these species at tidal heights of 1 m above chart datum (*L. digitata*) or even

2 m above chart datum (*S. latissima* – as *L. longicruris*) and with high densities down to -7 m and -8 m, respectively. We could not replicate these observations at any site we visited in Lobster Bay. Indeed, kelp dominance was observed beginning only at about 5 m depth.

At some sites, *F. serratus* has transformed one low canopy-forming species, *C. crispus*, into an understorey plant (Garbary *et al.* 2021), greatly reducing or replacing populations of *L. digitata* and *S. latissimma*. The cause of this change is an open question. The potential for overharvesting of *C. crispus* was initially pointed out by MacFarlane (1952) and then alluded to by Haggerty and Hellenbrand (1976). The extensive surveys of *Chondrus* beds in the low intertidal zone and shallow subtidal zone down to about -4 m (12 feet) by Haggerty and Hellenbrand (1976) in Lobster Bay and east of Cape Sable Island did not record *Fucus serratus*. Pringle and Mathieson (1987) and Vandermeulen (2013) pointed out that the commercial harvests had declined extensively by 2003 from peak harvests in 1981. Thus, the extensive bands of *F. serratus* that we observed intertidally in 2020 (Garbary *et al.* 2021), and here in 2021, have developed since the mid 1970s with the first evidence of this being the 1977 transects by Dale (1982) and Novaczek and McLachlan (1989). The shore zone where one would expect to see *C. crispus* as a canopy has been replaced by *F. serratus*. Even where we observed healthy populations of *C. crispus*, it occurred as an understory beneath *F. serratus* and *A. nodosum*, e.g., Surettes Island (Garbary *et al.* 2021). The absence of grazing patellid limpets in the northwestern Atlantic Ocean may also explain the the upward migration of invasive *F. serratus*. In western Europe, *Patella vulgata* is a major grazer on *F. serratus* and its experimental removal facilitated the upward colonization of the fucoid (Boaventura *et al.* 2002). In addition, experimental canopy removal of *A. nodosum* led to the long-term colonization by other fucoids including *F. serratus* (Jenkins *et al*. 2004); the commercial harvest of *A. nodosum* in southwestern Nova Scotia may be having a similar effect.

CLIMATE CHANGE IN SOUTHWESTERN NOVA SCOTIA

One might invoke global warming as the possible cause in kelp decline in Lobster Bay. Considerable warming has occurred since the 1960s in air temperature in Nova Scotia, although Yarmouth has

shown less temperature increase than other parts of the province, i.e., 0.6°C vs up to 1.5°C elsewhere (Garbary and Hill 2021). In addition, seashores on this part of Nova Scotia are prone to morning fog (Novaczek and McLachlan 1989) that can persist to late morning. Kelp declines elsewhere along the Atlantic coast of Nova Scotia have been attributed to increased sea surface temperature (SST) associated with an ocean warming hotspot (Hobday and Pecl 2014, Filbee-Dexter *et al.* 2016). However, the upper summer maxima of around 14°C (increase of 0.9°C in Lobster Bay and southwestern Nova Scotia (Lauzon-Guay *et al.* 2021, Scrosati and Ellrich 2020) would not restrict low intertidal or shallow subtidal kelp populations, where 15°C can maintain healthy kelp sporophytes (e.g. Andersen *et al.* 2013, Simonson *et al.* 2015) and gametophytes (Dieck 1993).

Over the last 70 y, the mean annual air temperature in Nova Scotia has risen about 1°C (Garbary and Hill 2021). This change occurred as a step-change between 1997 and 1998 (Table 3). The mean change was only 0.6°C at Yarmouth; however, the extreme annual low temperature rose almost 2.0°C and the extreme highs 1.2°C. The warmer winter temperature may facilitate colonization of the intertidal zone by *F. serratus* that had started by at least 1977 (i.e., Dale 1982, Novaczek and McLachlan 1989). Regardless, the temperature increase did not occur until at least 20 years later, and this coastline was only recognized as an ocean-warming hotspot well into the current century (Hobday and Pecl 2015, Filbee-Dexter *et al.* 2016).

The change in mean annual air temperature between 1961 and 1997 for Nova Scotia as a whole, and the Yarmouth area in particular, were not significant (Garbary and Hill 2021); indeed, the slope of the linear regressions over this period and going back to the early 1950's was typically not significant, and often negative, e.g., Table 3. Subsequent increases in air temperature of 0.7°C in mean annual air temperature as a step change in 1998 is less than the February increase of 1.4°C (i.e., from -3.4±1.6°C in 1961-1997 to -2.0±1.5°C in the 1998-2021 period; mean±s). At a mean air temperature of -2°C, *F. serratus* would be much less susceptible to freezing; hence, intertidal colonization would be more likely. The greater extent of *F. serratus* in the low intertidal zone would facilitate greater recruitment into the adjacent shallow subtidal areas where kelp communities historically existed. Overall, changing air and water temperatures in Lobster Bay are unlikely to be the direct

Table 3 Changes in metrics for air temperature 1950–2021 at Yarmouth Airport (data from Environment Canada: climate.weather.gc.ca/historical_data/search_historic_data_e.html). Note: differences between the means for early (1950-1997) and late (1998-2021) periods are significant (Student's-*t* test, P < 0.01). Linear regressions for each time-period metric generate slope (+ or –), R2, and P). Linear regressions calculated using online GraphPad calculator (www.graphpad.com/quickcalcs/linear2/); significant P-values indicated in bold.

Temperature metric	1950–1997 (°C)	1998–2021 (°C)	Temperature elevation (°C)
Annual mean	6.9±0.6 (–, 0.036, 0.196)	7.5±0.8 (+, 0.058, 0.266)	0.6
Extreme annual minimum	–17.2±2.4 (–, 0.062, 0.86)	–15.4±1.9 (+, 0.140, 0.072)	1.8
Extreme annual maximum	26.5±1.7 (+, 0.054, 0.111)	27.5±1.6 (+, 0.068, 0.217)	1.0
Mean daily minimum of coldest month	–7.8±1.5 (–, 0.139, **0.009**)	-6.6±2.0 (+, 0.067, 0.223)	1.2
Mean daily maximum of warmest month	21.0±0.9 (+, 0.111, **0.021**)	22.2±0.9 (+, 0.501, **0.0001**)	1.2

cause of kelp decline; however, such increases may have shifted the competitive interactions between kelp and *F. serratus* towards the latter species.

WHY DID THE IRISH MOSS HARVEST DECLINE?

We propose the following scenario to explain the change in community structure since the 1950s as described in various publications (e.g., MacFarlane 1952, Edelstein *et al.* 1972, Hagerty and Hellebrand 1976, Sharp and Semple 1980). In the early 1950s *F. serratus* was restricted to offshore sites in the Tusket Islands. Extensive harvesting of *C. crispus* opened both low intertidal and shallow subtidal zones in Lobster Bay, creating a favourable habitat for *F. serratus*. Overharvesting associated with rakes with narrowly spaced tines (3.5-5 mm spaced tines vs 7-12.5 mm spaced tines) removed both mature and immature fronds, and may have damaged the holdfasts to limit bed recovery (Pringle and Semple 1978, review by Vandermeulen 2013). Beginning in the late 1990s this may have been exacerbated by climate change in which

hotter summer days resulted in bleaching events as observed on the South Shore of Nova Scotia (Vandermeulen unpublished). MacFarlane (1952) described a harvest zone of *C. crispus* of about 30 ft (10 m) that was suitable for raking. Once *F. serratus* became established at a site, it became a canopy species at many sites, above the beds of *C. crispus* and hence limited the area available for raking.

POTENTIAL RISK TO ROCKWEED POPULATIONS

The reduction of landings of *C. crispus* in the 1970s based on overharvesting (Vandermeulen 2013) may have been associated with establishment of *F. serratus* (i.e., Dale 1982, Novaczek and McLachlan 1989). Subsequent changes in landings of *C. crispus* were likely driven by global changes in the market for carrageenan (Vandermeulen 2013). Our intertidal surveys in 2020 (Garbary *et al.* 2021), and subtidal surveys described here for 2021, show that *F. serratus* has now largely replaced the low intertidal and shallow subtidal (to about 5 m depth) populations of kelp, with *C. crispus* as the primary understory. The Chebogue Point transect by Novaczek and McLachlan (1989) indicated a clear demarcation of *F. serratus* and *A. nodosum*. The transect at Chebogue Point (Garbary *et al.* 2021) and shore surveys at Pubnico Point and Lower Wedgeport show that this is no longer the case, and there has been considerable upward movement of *F. serratus* into shore elevations once dominated by *A. nodosum* and *F. vesiculosus* both attached to boulders and as an epiphyte on *A. nodosum*.

The continued upward movement of *F. serratus* may be facilitated by climate warming with an increase of annual air temperature at Yarmouth post-1998 of about 0.6°C relative to 1950-1997 (Table 3). The warming trend is generally more pronounced for winter where temperature metrics for the coldest months (December through February), having increased daily minimum temperatures of 1.8°C, and with mean air temperature currently about -2 to -3°C. The stability of the temperature regime in the early period is shown by the low values for R^2 (max 0.139). In addition, four out of five metrics for the post-1998 period were not significant. These data show that the temperature increase occurred well after the decline of the *Chondrus* harvest and the likely increase in the populations of *F. serratus*. Thus, while possibly facilitated by climate change, we propose that harvesting of *C. crispus* contributed to the spread of *F. serratus* and to the decline

of this harvest industry in southwestern Nova Scotia (Vandermeulen 2013). In addition to the decline of kelp abundance in this area, our observations of the intertidal abundance of *F. serratus* in Lobster Bay (Garbary *et al*. 2021) raises the possibility that raking of *A. nodosum* near the lower margin of its zone may be facilitating the further incursion of *F. serratus* and reducing the area of intertidal zone dominated by *A. nodosum*. We consider this a potential threat to the *Ascophyllum* harvest industry. This points to the need for more government oversight of the harvest industry, and for suitable control sites that are unharvested and suitable for research by investigators unaffiliated with industry (e.g., Vandermeulen 2013, Lotze *et al*. 2019, Fass 2021, Lauzon-Guay *et al*. 2021).

Acknowledgements Our survey of Lobster Bay was facilitated by boat support from Charlene LeBlanc at the Municipality of Argyle. Bernice d'Entrement of the Musée des Acadiens des Pubnicos kindly provided advice on place names. SJ Hawkins provided valuable comments during review. MF was supported by postgraduate scholarships from St. Francis Xavier University, the Government of Nova Scotia, and Natural Sciences and Engineering Research Council of Canada (NSERC). The research was funded by NSERC Discovery Grants to DJG.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 485-521

POPULATION CHARACTERISTICS AND MOVEMENTS OF AMERICAN LOBSTERS (*HOMARUS AMERICANUS* H. MILNE-EDWARDS, 1837) CAPTURED IN THE MINAS REGION OF THE INNER BAY OF FUNDY, NOVA SCOTIA

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ABSTRACT

Tidal power potential is being explored for Minas Passage, the body of water that connects Minas Basin to the Bay of Fundy (BoF). The Minas Channel−Minas Basin area of the BoF supports an American lobster fishery of ~200*t* worth $2.0-3.0 million/year. Three studies in the region were conducted during 2008-2018 to evaluate population characteristics and movement of lobsters for future assessment of impacts from tidal power development. A total of 12,327 lobsters captured in commercial and experimental lobster traps were examined for carapace length (CL), sex, and reproductive condition. Of these, 5614 marked with exterior streamer tags during 2008 and 2017 were released for recapture information from fishers. During 2011-2013 and 2017-2018, 125 and 50 lobsters, respectfully, were marked with acoustic tags and monitored in Minas Passage and Minas Basin with acoustic receivers deployed by Acadia University, the Mi'kmaq Conservation Group, the Ocean Tracking Network, and Fundy Ocean Research Center for Energy. Carapace length of males and females ranged from 41-200 mm and 51-216 mm and mean CL varied from 87.1-121.0 mm and 88.3-115.7 mm, respectively. Male: female ratios ranged from 1.0:0.6-1.0:1.2. Mean daily movement varied from 0.33 km/d to 1.21 km/d. Females released larvae during July, egg extrusion began in October, and proportion of berried females peaked in December at 50.4%. Experimental trap catches, streamer tag returns, and acoustic detections indicated that lobsters were spread evenly over the

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sampled area in summer but movement into Minas Passage occurred during autumn where the lobsters remained for winter. Movement of berried females into Minas Passage is possibly a local life history strategy that enhances development rate of attached eggs in the relatively warmer water of this region during winter (+1.0°C). Lobsters marked with streamer tags migrated throughout the BoF and were reported from traps off Advocate and as far as Grand Manan and SW Nova Scotia (200+ km).

INTRODUCTION

The fishery for American lobster (*Homarus americanus* H. Milne-Edwards, 1837) is the largest by value in Atlantic Canada. Between 2015-2024, Canadian lobster landings varied from 90,000 to 106,000*t* (Goldstein *et al*. 2026) and the annual value to the Canadian economy was approximately $3 billion with large exports to the United States, the United Kingdom and China. Landings from Lobster Fishing Areas (LFA) 33-35 (Fig 1; Halifax-Inner Bay of Fundy) in 2018 were 31,863*t* with a landed value of $502 million (DFO 2021). The Minas Channel to Minas Basin lobster fishery has annual landings of approximately 200*t* and during 2018 with a dockside price of $6.50/lb was worth $2.86 million. A total of 29 fishers, operating out of Parrsboro on the north side of Minas Basin, Delhaven on the south side of the Basin and Halls Harbour in Minas Channel share the fishery (Morrison 2014). This well-defined fishery operates in Minas Channel to Minas Basin (Fig 1, LFA 35) during May 1-July 31 and October 15-late December. Although the fishery in this region is open during winter; fishing is not possible because of drifting ice. Fishing is also difficult because the large tides (range 11-16 m) and strong currents (3-6 m/s) cause lobster buoys to submerge except around high water and low water slacks; periods of about 2-4 hours in each case. Trap hauls average about 100/day/fisher but daily yields are high both in the spring-summer and autumn (average 400-500 kg; Dadswell *et al.* 2009). In LFA 35 the minimum allowable retention size was 82.5 mm carapace length (CL) during our 2008 study but was raised to 88.5 mm CL before the 2017-2018 study. Lobsters sampled from fisher's traps ranged from 41-216 mm CL and the proportion of shorts (lobster <88.5 mm CL) to markets was about 1: 2 during both 2008 and 2017. The sex ratio in the catch is approximately 1:1 and there is a high proportion of berried females (DFO 2021).

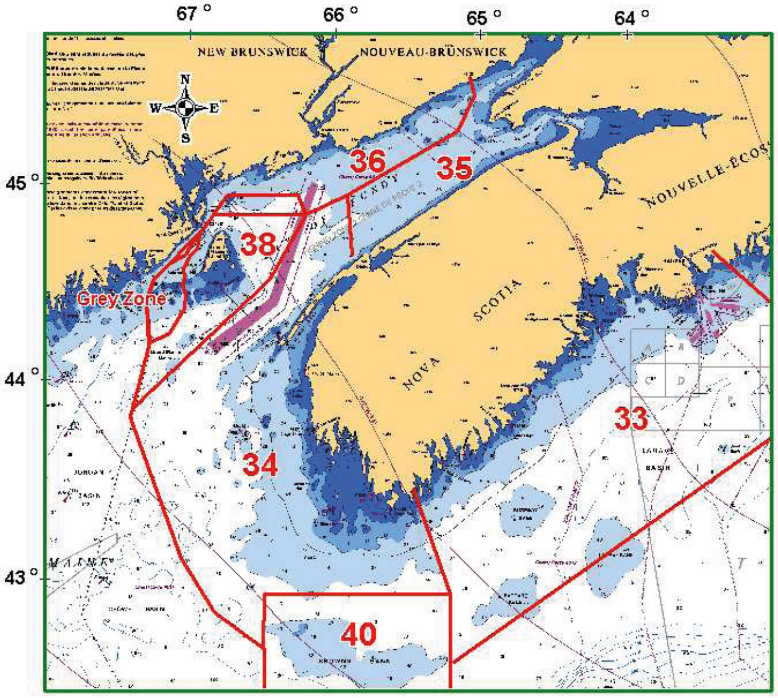


Fig 1 **Lobster fishing areas in western Nova Scotia and the Bay of Fundy. The Minas Channel–Minas Basin fishery is in LFA 35 (after DFO 2021).**

Brief Synopsis of American Lobster Biology

The American lobster is a member of the Crustacean clawed lobster family, Nephropidae (Goldstein *et al*. 2026). The basic body plan consists of two parts: the cephalothorax which represents the fusion of head and thorax; and the abdomen (Cobb 1976). The cephalothorax is covered by a heavy, fused shell or carapace, but the abdomen is flexible because each segment has its own shell. It has two, large forward projecting claws which it uses for defense, prey capture and to process its food and habitat. There are four sets of walking legs in the rear section of the cephalothorax and a large tail fan consisting of flattened appendages called the uropods and the telson. With these appendages lobsters can move rapidly, walking over the bottom or swimming to avoid predators, capture prey or move long distances to remain in preferred temperatures and salinity for growth, reproduction, and survival (Campbell 1986). They feed on most any kind of benthic organism including but not restricted to marine worms (Polychaeta), isopods and decapods,

particularly crabs, bivalve and gastropod mollusks, echinoderms including sea urchins, fish, and plant matter (Goldstein *et al.* 2026). They are also scavengers and can be cannibalistic.

The American lobster is distributed from Labrador to North Carolina and found from low tide to depths of 400 m (Cobb 1976, Wahle and Steneck 1991). At the northern extent of its range, the lobster occurs inshore at relatively shallow depths (0-100 m) but in the middle and southern portions of its range inhabit deeper water and offshore to marine canyons (100-400 m). Lobsters occur on most any substrate from clay to cobble but generally select habitat with rocks where they can hide in crevices or burrow under them to hide from predators. With their large claws numerous feet and powerful tails lobster dig away the substrate to make tunnels (Cobb 1976, Berrill and Stewart 1973). The tunnels are used to hide from predators such as wolf fish, cod, flounder, crabs or other lobsters and for protection when molting during reproduction.

Lobsters grow by molting their external shell (ecdysis; Cobb 1976). Molting can occur two or three times annually in young lobsters but for adult lobster takes place once annually usually during the warmest period of the summer (June-August, Goldstein *et al*. 2026). After molting their shell is soft and the lobster is especially vulnerable to predation. Growth of lobsters in the Bay of Fundy (BoF) is relatively slow compared to growth in other Atlantic coast regions because of the lower annual accumulation of degree days in the cooler Fundy waters. Lobsters in the BoF take about six years to reach 81 mm CL and another 2-3 years to attain commercial size (88.5 mm CL) and sexual maturity (90-100 mm CL; Campbell 1983).

Most mature lobster females reproduce only once every other year, so the maximum portion of egg-bearing females found in a local population seldom exceeds 50% annually (Cobb 1976, Campbell 1983, Waddy and Aiken 1986). Mating only takes place when the female is in the soft-shell condition immediately after molting. She enters a males' burrow, molts, is mounted by the male and sperm transfer occurs. The female then stores the sperm in seminal vesicles. The male continues to defend the burrow and protect the female until her shell hardens at which time she departs. About 2-3 mouths later the female makes her own burrow or finds a place to hide and at night turns on her back and releases her eggs which pass through the seminal vesicle, are fertilized, and as they are released through the oviduct, the

female 'glues' them to the swimmeret appendages on the underside of her abdomen. Individual females release between 5,000-40,000 eggs depending on size (Koopman *et al.* 2015). The female is now in the 'berried' condition and she carries the developing eggs on her abdomen for nine to ten months until the larvae are ready to hatch during June-August (Perkins 1971). About a quarter of her eggs hatch with the larvae released each night (Pandian 1970).

American Lobster Movements

During the first years of their life, American lobster juveniles remain hidden in or near their shelter to avoid predation (Wahle and Steneck 1991). When larger, lobster migrate to shallow depths in summer and deeper depths in winter and in numerous studies approximately 75% moved <15 km (Campbell 1986, Robichaud and Lawton 1997). Similar research done in the southern Gulf of St. Lawrence concluded that of 42,445 lobsters that had been tagged and released with 8503 recoveries, most had moved only 2-19 km from their release points (Comeau and Savoie 2002). In BoF, the Gulf of Maine, the offshore regions of the Scotian Shelf and off New England, however, some lobsters undertake long distance migrations of 100 km or more (Campbell 1986, Campbell and Stasko 1986, Robichaud and Lawton 1997). The record distance for travel to date was 798 km by a lobster tagged off Alma in the inner BoF and recovered on the southern side of Georges Bank.

The Environment of the Minas Region

Minas Basin (45°19'N, 64° 00'W) is a mega-tidal, cul-de sac marine embayment on the eastern side of the inner BoF and is semi-enclosed by the Province of Nova Scotia. The triangular basin is 80 km long and 29 km wide at the base and ~2000 km^2 in area. It consists of the central Minas Basin proper, Cobequid Bay the eastern extremity inside Economy Point, and the Southern Bight (Fig 2). Maximum depth in the Basin is 17 m at low tide. Minas Basin has the largest recorded tides in the world (mean 11 m, maximum 17 m; Garrett 1972) and at low tide about one third of the Basin area (670 km^2) is exposed as tide flat (Bousfield and Liem 1959). The tidal regime is semi-diurnal and an estimated 3 x 10^9 m^3 of water flows in and out of the Basin with each tide (Karsten *et al.* 2008). Because of the extreme tides the water column is homogeneous for temperature and salinity. Sea surface temperature (SST) ranges from a peak of 16-22°C in summer (August-September; Bousfield and Liem 1959) to -1.5-0.0°C in winter (February; Sanderson

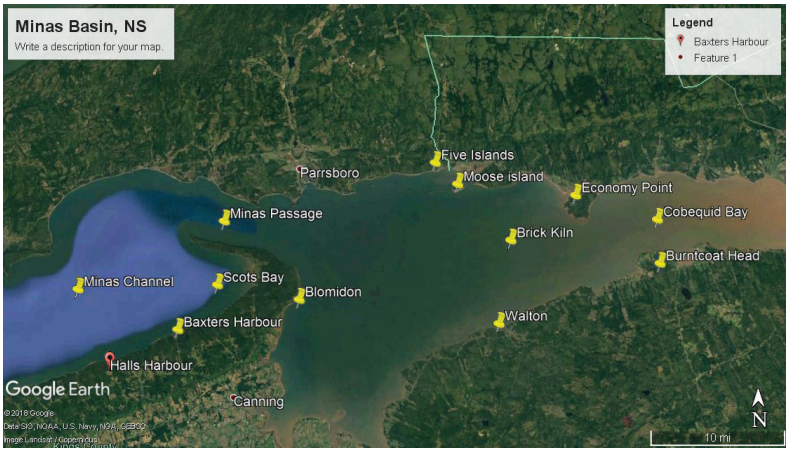


Fig 2 **Minas Channel, Minas Passage, and Minas Basin at the eastern extent of the inner Bay of Fundy. Locations highlighted with yellow markers are referred to in the text.**

and Redden 2015). Winter is characterized by drifting ice pans up to 5 m thick which in some years cover most of the Basin from January to March and severely scour the substrate of the intertidal zone (Desplanque and Mossman 1998).

Minas Passage (45°20'N, 65°40'W) connects Minas Channel of the inner BoF with Minas Basin (Fig 2). It is 15 km long and ~5 km wide with low tide depths of 35-115 m. Tidal velocities from 3-6 m/s occur in Minas Passage during falling and rising tides and large gyres have been identified around Cape Split and Cape Blomidon (Greenberg 1984). The strong tidal velocities have scoured most of the substrate of Minas Passage to bedrock (AECOM 2009).

Minas Passage has SSTs of 14-16°C from June to October (Bousfield and Liem 1959) and because of extensive upwelling the water column is isothermal from bottom to surface (AECOM 2009). The upwelling also causes Minas Passage to be warmer in winter than Minas Basin or Minas Channel. Winter temperatures range from 6.0°C in December to 1.0°C in March (Keyser *et al.* 2016).

Minas Channel (45°10'N, 65°50'W) connects the inner BoF to Minas Passage (Fig 2). It is 40 km long and 15-30 km wide with low tide depths of 10-60 m. Tidal velocities are similar to Minas Passage. SSTs in the Channel are the same as Minas Passage in summer but colder during winter.

Development of Tidal Power in Minas Passage

The Fundy Ocean Research Center for Energy (FORCE) has developed a reserve for energy and environmental research in Minas Passage where companies can test tidal power hydro-kinetic devices and study their effects on the environment (Fig 3, FORCE 2017, Bangley *et al*. 2022). FORCE has an array of five acoustic receivers on their research site and the Ocean Tracking Network (OTN) has an array of 12 receivers across Minas Passage between Cape Sharp and the Cape Split headland (Fig 3).

The development of tidal power in Minas Passage has been a concern for regional fishers because of the unknown and potentially deleterious effects caused by the devices. Because of this concern lobster fishers, Big Moon Power Canada, the Marine Institute of Natural and Academic Sciences, the Mi'kmaw Conservation Group, FORCE, and Acadia University partnered to study the biology and movements

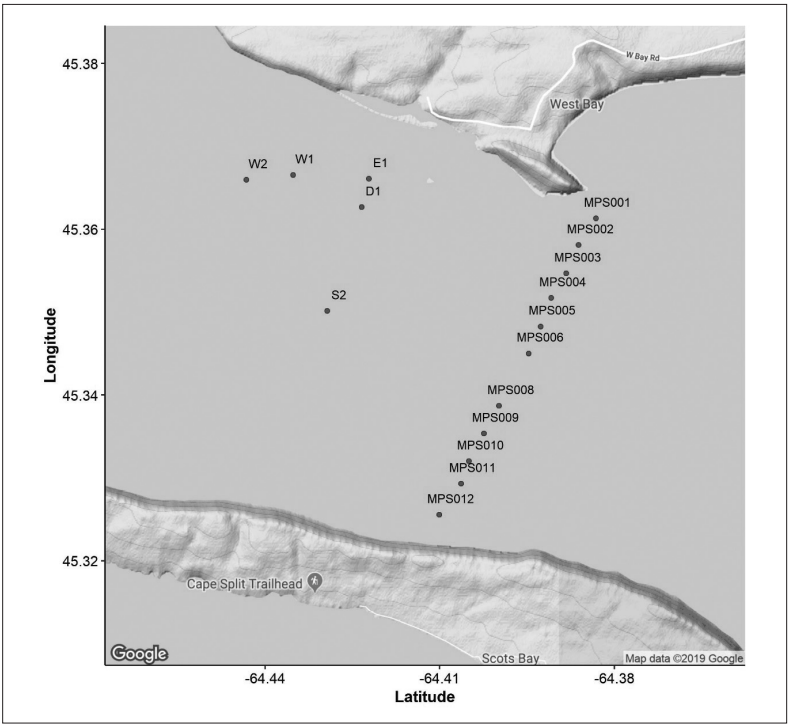


Fig 3 Positions of VEMCO VR2W receivers deployed by the Ocean Tracking Network (MPS001-MPS012) and by FORCE at their tidal power research site (D1-W2) in Minas Passage during 2008–2018.

of American lobster in Minas Basin, Minas Passage, and Minas Channel to establish a baseline of knowledge. The information gained will be used for comparison to the Minas region lobster population in the future to determine if any significant effects from tidal power development may have occurred.

METHODS

This study involved five stages. Sampling of fisher's lobster traps in Minas Passage and Minas Channel for catch data and lobster biological characteristics was conducted during May-October 2008 and short lobsters (<82.5 mm) and berried females were tagged with streamer tags (Dadswell *et al.* 2009). During 2011-2013 lobsters were obtained from fisher's traps in Minas Basin, tagged with acoustic tags, and monitored with acoustic receivers deployed in Minas Passage by Acadia University, and the FORCE and OTN arrays (Morrison *et al.* 2014). During November-December 2017 catches from commercial traps set in Minas Channel, Minas Passage and Minas Basin were sampled and lobsters examined to determine biological characteristics. Lobsters supplied by fishers from their traps were tagged with streamer and acoustic tags. Then, in 2018 experimental lobster traps (Fig 4) and acoustic receivers (Fig 5) were deployed in Minas Basin and Minas Passage and captured lobsters were examined for biological characteristics. Finally, movement data collected from lobster sampling, tag returns, and acoustic detections from all acoustic receivers in the study area during 2008-2018 were analyzed for distance moved, time at large, and direction of movement.

Lobster Tags

Streamer tags used were FLOY yellow plastic tags with a printed ID number and return address on each tag. Tags were inserted into the flesh on the underside of the abdomen between the second and third segments. Approximately 10 cm of tag was obvious to view on each side of the abdomen (Fig 6). Plastic streamer tags have excellent retention (~98%), do not affect the lobster physically, and are usually not lost during molting and other activities (Scarratt 1970, Comeau and Mallet 2003).

Acoustic tags used were VEMCO V-13 tags during 2011-2013 and VEMCO V9-2H tags during 2017-2018 (VEMCO 2019). VEMCO V-13 tags are 45 mm long. At a signal phase of 60-120 seconds, they

have a life span of 286 days. VEMCO V9-2H tags are 9 mm in diameter, 24 mm in length and weigh 2.9 gm in water (VEMCO 2019). At a signal phase of 180 seconds, they have a life span of 324 days. Underwater reception range of acoustic pings was 0-400 m depending on current speeds (Morrison 2014).

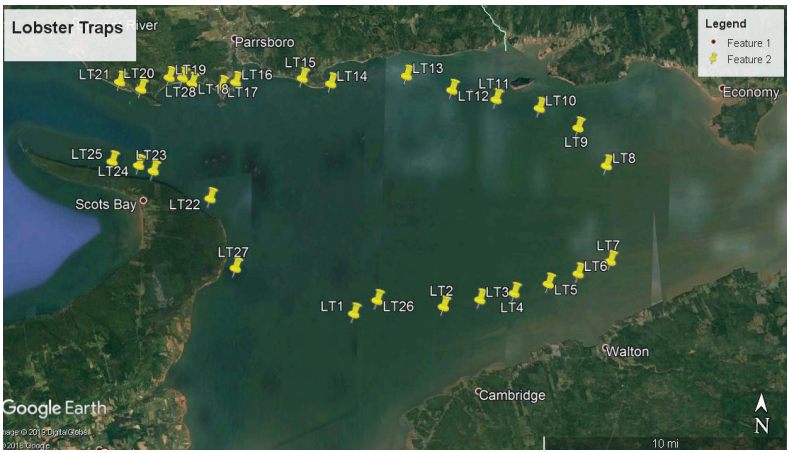


Fig 4 Distribution of experimental lobster traps in Minas Passage and Minas Basin during August 6-October 14, 2018.

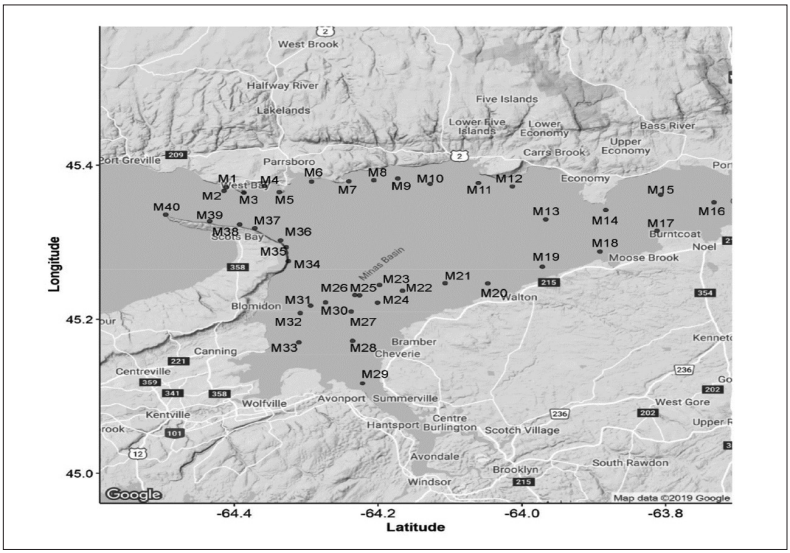


Fig 5 Positions of VEMCO VR2W receivers (M1-M40) in Minas Passage and Minas Basin deployed during April-December 2018.



Fig 6 **Lobster tagged with a yellow FLOY streamer tag through the underside of the abdomen. This lobster was MCG0473. It was a hard-shelled, 70 mm CL male captured off Halls Harbour in Minas Channel on November 3, 2017. To date it has not been recaptured.**

The tag was attached to the dorsal surface of the lobster carapace with 5-minute epoxy resin adhesive (Fig 7). First the lobster was placed on a level, damp surface (wet paper towel) to reduce desiccation. Then the dorsal surface of the carapace was washed with isopropyl alcohol and allowed to dry for five minutes. The epoxy resin was mixed and applied to the carapace surface and the tag pressed into the epoxy. The epoxy was allowed to air-dry for one-half hour at which time the lobster was released back into the sea. Release sites were fixed for latitude and longitude using a handheld GPS meter (Garmin Etrex HTC; accuracy±3 m).

Lobster Sampling and Tagging 2008-2018

During 2008 lobster traps set by fishers were allowed to soak for time periods between 1-3 days. For at-sea sampling personnel went aboard fishing vessels when pre-set lobster traps were hauled. Captured lobsters were counted, measured for CL, examined for sex and whether females were berried and assessed for molt stage (soft/hard). Sampling was conducted during June 1-July 31 and October 1-2 in Minas Channel and Minas Passage (Fig 2). Short lobsters (<82.5 mm CL) and berried females were tagged with FLOY streamer tags (2633).

During November 2011 and December 2012 traps set by fishers in Minas Basin were used to obtain lobsters for tagging with VEMCO



Fig 7 **An acoustic tag (VEMCO V9-2H) attached to the dorsal portion of a lobster carapace using epoxy adhesive. This was acoustic lobster 986 which was a berried female of 145 mm CL. She was released on the north side of Minas Passage on November 1, 2017, and was detected at the OTN line from November 6-22, 2017, then at the FORCE site on December 1, 2017. During 2018 she was detected numerous times at the middle to northern end of the OTN line before returning to the FORCE site in late July then back to the OTN line in August. During a period of 293 days, she moved a minimum distance of 8.8 km.**

V-13 acoustic tags. A total of 125 lobsters were released with acoustic tags attached, 85 in 2011 and 40 during 2012. An additional 29 VEMCO VR2W acoustic receivers were deployed in Minas Passage by Acadia University on the westward side of the FORCE site (Morrison 2014). Detections were obtained from the ACADIA, FORCE, and OTN receivers which facilitated range testing data with reference to current speed. Receiver spacing allowed for maximum coverage and optimization of receptions (Clements *et al.* 2005).

During November-December 2017 lobster traps pre-set by fishers in Minas Basin, Minas Passage and Minas Channel were again sampled. Protocol and data taken on lobsters was the same as in the 2008 study. Lobsters were tagged with FLOY streamer tags (2981) and VEMCO V9-2H acoustic tags (50). Acoustic tags were released during November 1-26, 2017.

During August 6-October 13, 2018, 28 experimental lobster traps were deployed in Minas Passage and Minas Basin (Fig 4). Traps used were the standard, commercial type like those used by fishers during the 2008 and 2017 surveys. Lobster catches were analyzed for CL of males and females, sex ratio, proportion of berried females and molt stage. Population characteristics found during 2017 and 2018 were compared using Student's t-test ($p<0.05$; Zar 2010).

Deployment of Acoustic Receivers 2011-2018

A total of 11 VEMCO VR2W acoustic receivers were deployed by OTN at their Minas Passage array from Cape Sharp on the north side of Minas Passage to the Cape Split headland on the south side. Data was available from November 1, 2011, to November 20, 2018. Downloads occurred approximately every four months. Receivers were titled MPS001-MPS012 (Fig 3). MPS007 was lost after June 2018. Range testing of these receivers indicated that acoustic tag receptions were lost when current speeds exceeded 1.5 m/s or for about 80% of each tidal cycle (Morrison *et al*. 2014). On the other hand, when current speeds were low (twice every 6 h) receptions were obtained from distances of 200-400 m.

Five (5) VEMCO VR2W acoustic receivers were deployed by FORCE at their tidal, hydroelectric test site in Minas Passage. The receivers were deployed and data was available from November 1, 2011, to August 23, 2018. Receivers are W1, W2, E1, D1 and S2 (Fig 3). An additional array of 29 VEMCO VR2W acoustic receivers were deployed by Acadia University between Minas Channel and Minas Passage during 2011-2013 (Morrison 2014).

Forty VEMCO VR2W acoustic receivers were deployed on moorings in Minas Basin and Minas Passage during April 4-December 16, 2018 (Fig 5). Receiver latitude and longitude at deployment were determined with a handheld Garmin meter. Receivers were visited once a month and downloaded to guard against loss of data.

Analysis of Lobster Movements in Minas Basin, Minas Passage and the Bay of Fundy

Catch/trap was determined from data collected between June 1-October 2, 2008, and August 8-October 14, 2018. The 2018 catches were further analyzed for season and % females. Movement of lobsters marked with streamer and acoustic tags were analyzed for direction, time at large, and distance of movement. Acoustic receptions in Minas Passage and Minas Basin were analyzed with the R-statistics package (R Core Team 2013) for number of detections, acoustic tag identification, duration and time of presence near each receiver.

Tag returns from commercial fishers and study sampling were mapped using Google Earth and analyzed for start and end point of movement, movement direction, and distance traveled. Streamer tag returns from the 2008 study (Dadswell *et al*. 2009) were incorporated with 2017-2018

tag returns to provide further information on long-distance movements in the Bay of Fundy.

RESULTS

Lobster Population Characteristics

A total of 971 fisher trap hauls were monitored during June 1-October 2, 2008, in Minas Passage and Minas Channel. The mean lobster catch was 4.73/trap. In 2018 the 28 experimental traps in Minas Basin and Minas Passage were monitored every two to three days during August 8-October 14. Mean lobster catch was 9.75/trap in Minas Basin and 17.36/trap in Minas Passage.

In 2008 a total of 2633 lobsters were examined for CL, sex, reproductive stage and molt stage, 1196 between June 9-July 30 and 1142 on October 5-6 (Table 1). Carapace length ranged from 55-143 mm for sampled male lobsters and 57-136 mm for sampled females. Mean CL of males during June-July was 87.1 mm compared to 91.1 mm in October. Mean CL of females was 88.3 mm during June-July and 96.4 mm in October. Mean CL of berried females was 100.7 mm during June-July and 101.9 mm in October.

During 2017-2018 a total of 9,694 lobsters were examined for CL, sex, reproductive stage and molt stage; 2413 during November 2-December 22 and 7281 during August 8-October 14 (Table 1). Carapace length of sampled male lobsters in 2017 ranged from 41-165 mm; sampled females, 63-216 mm (Fig 8). Carapace length of males in the 2018 sample ranged from 60-200 mm; females, 67-178 mm.

Table 1 Comparison of sample size (N), mean and range of carapace length of all males (M), all females (F), and berried female (BF) lobsters and the sex ratio (M: F) during 2008 and 2017-2018. Minimum carapace length for commercial take in 2008 was 82.5 mm but was increased to 88.5 mm before 2017-2018.

Sample Month/Year	Catch N	Mean Carapace Length M mm	F mm	BF mm	Range M mm	F mm	Sex Ratio M:F
06-07/2008	1196	87.1	88.3	100.7	54-133	57-136	1.0:0.9
10/2008	1142	91.1	96.4	101.9	55-133	51-124	1.0:0.6
11-12/2017	2413	101.7	102.5	124.1	41-165	63-216	1.0:1.2
08-10/2018	7281	121.7	115.7	125.7	60-200	67-178	1.0:0.6

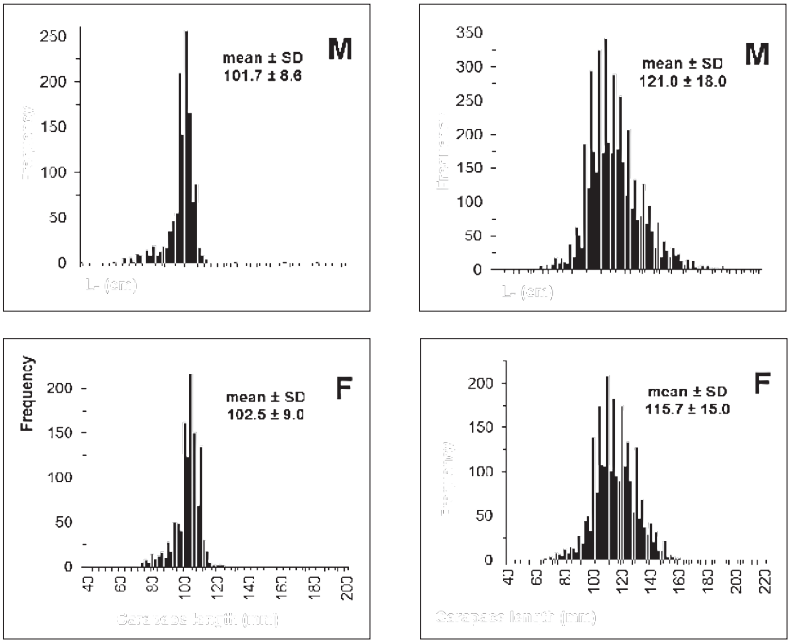


Fig 8 **Carapace length (mm) frequency of American lobster tagged in Minas Channel to Minas Basin from November–December 2017 and Minas Passage to Minas Basin during August-October 2018. Top (M=males 2017, n=1,221; 2018, n=4,708); bottom (F=females 2017, n=1192; 2018, n=2,573). Lengths grouped in 2 mm bins.**

Mean CL of males and females were 101.7±8.6 mm and 102.5± 9.0 mm in 2017 and 121.0±18.0 mm and 115.7±15.0 mm in the 2018 sample, respectively (Fig 8). Mean CL of males sampled during August-October 2018 was significantly larger than mean CL for males sampled during November-December 2017 as were females (t-test, $p<0.01$). Mean CL of berried females during November-December 2017 was 125.1 mm and was significantly greater than the mean CL of non-berried females from the same sample (Fig 9; t-test, $p<0.01$). There were too few berried females in the 2018 sample for comparison to non-berried females. The proportion of females in the November-December 2017 sample was greater (M: F=1.0: 1.2) than the proportion of females in the August-October sample (M: F=1.0: 0.6, Table 1).

Statistical comparison of lobster population characteristics between 2008 and 2017-2018 was not possible because the minimum commercial CL during 2008 was 82.5 mm (shorts) but was raised to 88.5 mm by 2017-2018. Also, because the minimum CL was raised, lobster fishers had

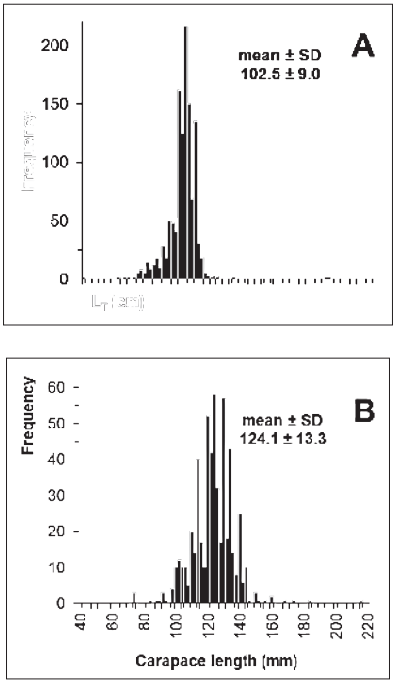


Fig 9 **Carapace length (mm) frequency of female non-berried (A, n=1,192) and berried (B, n =557) American lobster tagged in Minas Passage and Minas Channel from November to December 2017. Carapace lengths are grouped in 2 mm bins.**

to increase the size of the escape vents on their traps, which probably released more small lobsters during 2017-2018 before trap catches were examined. The mean CL of all 2008 lobster groups (males, females, berried females) were all lower than those observed in 2017-2018 although the CL range remained somewhat similar (Table 1).

Among samples taken during two-week periods from June-July 2008, August-October 2018 and November-December 2017, berried females represented 35.2% of females in June, declined to 5% of females in July, was <2.0% females during August-September, then steadily increased to 50.4% of females by December (Table 2). The proportion of soft-shell lobsters in the population also exhibited a seasonal cycle. Soft-shell lobsters were not observed during June but increased to 42.9% during late July and then decreased rapidly to 0.1-4.0% during August to December (Table 2).

Table 2 **American lobster sampled in Minas Channel to Minas Basin in biweekly periods during June to December, 2008-2018: total sample size, number of females and percent of total; number of berried females, percent of females and percent softshell.**

Period	Total Sampled	Females	% total	Berried	% Females	Softshell %
Jun 1-15	532	316	59.4	115	36.3	0.0
Jun 16-30	296	184	62.1	63	34.2	0.0
Jul 16-30	368	144	39.1	8	5.5	42.9
Aug 8-15	1306	578	44.2	1	0.1	0.4
Aug 16-31	2071	911	43.9	5	0.2	0.4
Sep 1-15	1609	592	36.8	7	0.4	0.3
Sep 16-30	1335	376	35.8	17	1.3	2.7
Oct 1-15	1051	344	32.7	24	6.9	3.9
Nov 1-15	994	534	53.7	191	35.7	0.1
Nov 16-30	995	436	43.8	200	45.9	0.1
Dec 1-15	220	141	64.1	54	38.3	0.1
Dec 15-22	772	460	59.5	232	50.4	0.2

Lobster Tagging

During June-October 2008 a total of 2633 Floy streamer tags were deployed in Minas Channel and Minas Passage in lobsters ranging from 45-130 CL mm. Of streamer tags deployed during 2008, 455 (17%) were returned from commercial fishers. None of the 2008 FLOY tagged lobsters were recovered during our 2011-2013 and 2017-2018 studies.

A total of 2981 Floy streamer tags were deployed on lobsters ranging from 41-185 CL mm from November 1-December 22, 2017, in Minas Channel, Minas Passage and Minas Basin. Streamer tag numbers were from 1-3000. Nineteen tags (0.06%) were either defective or missing. Of streamer tags deployed during 2017, 59 (2%) were returned by commercial fishers during 2017, five were returned during 2018 and one was recaptured during our study trap survey.

During the 2011-2013 study 125 acoustic tags were deployed on lobsters in Minas Basin during November 2011 and December 2012. Tags were deployed on 61 male (Range 90-144 mm CL), 43 females (Range 90-123 mm CL), and 21 berried females (Range 90-123 mm CL). Mean CL of berried females was 95.5 mm. Of the 125 acoustic tags deployed in Minas Basin a total of 40 (32%) were detected in Minas Passage during 2011-2013. Mean distance moved after release for all lobsters detected during 2011 was 0.33±0.34 km/day and for 2012 was 1.21±1.21 km/day. Female lobsters detected after release during 2012 moved 1.42±1.68 km/day.

A total of 50 acoustic tags were deployed in Minas Channel, Minas Passage and Minas Basin during November 1-26, 2017 (Table 2). Acoustic tags were deployed on six males (Range 86-105 mm CL), 5 non-berried females (Range 82-107 mm CL) and 39 (78.0%) berried females (Range 98-152 mm CL). Mean CL of berried females tagged was 131.3 mm. Of the 37 acoustic tags deployed in Minas Passage and Basin, a total of 23 (62.2%) were detected during 2017 or 2018 in Minas Passage. Of the 13 acoustic tags deployed in Minas Channel none were detected by Minas Passage receivers.

Detections on Acoustic Receivers During 2011-2013, 2017-2018

A total of 100,744 acoustic pings were recorded from 40 lobsters tagged in Minas Basin by receivers in Minas Passage at the ACADIA and OTN lines and at the FORCE site during 2011 to 2013. There were a total of 2335 acoustic pings at the northern portion of the OTN line, 1990 at the central portion, and 2980 at the southern end of the line. Since the acoustic data collected during 2011-2013 would have added little to the overall conclusions of our studies we chose to use only the 2017-2018 acoustic data for the detailed examination of lobster movement in the Minas region.

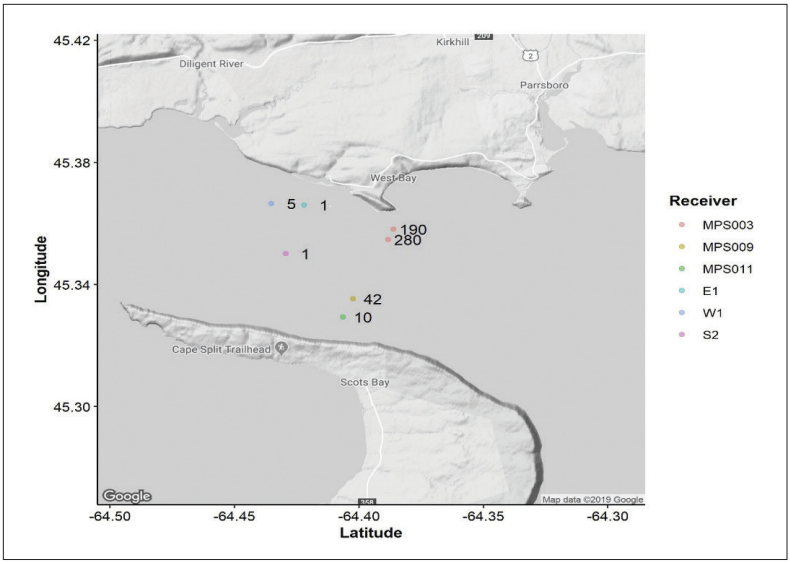


Fig 10 Total number of receptions of acoustic tagged lobsters at OTN line and FORCE site during 2017.

During November-December 2017 a total of 522 acoustic pings were recorded from tagged lobsters by receivers along the OTN line (Fig 10). These consisted of detections at receivers MPS002, MPS003, MPS009 and MPS011. Seven pings were recorded at the FORCE site from receivers E1, W1 and S2 during the same period. A total of five different acoustic tagged lobsters were detected at the Minas Passage receivers during November-December 2017 (Fig 11). Acoustic tags recorded were 986, 995, 1003, 1013 and 1019. Receptions commenced on November 1 immediately after tagged lobster were released in the vicinity. Lobsters 986, 1003 and 1013 remained near the receivers for extended periods, others only briefly (Table 3). Receptions at the OTN line consisted of three lobsters (two berried females and one male). Receptions at the FORCE site were from two other berried females.

A total of 6387 pings from acoustic tagged lobsters were recorded at OTN receivers during January-November 2018 (Fig 12). These consisted of receptions at receivers MPS1-MPS11. A total of only four pings

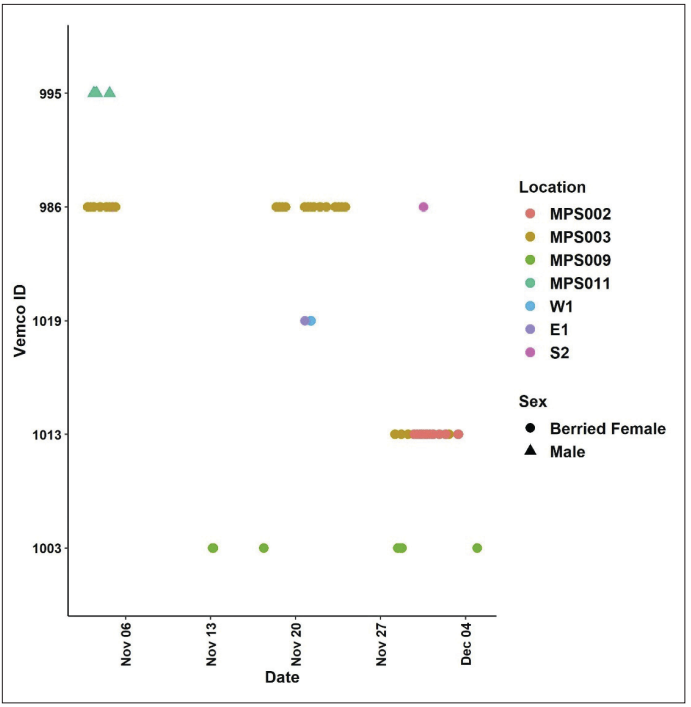


Fig 11 Receptions of individual acoustic tagged, sexed lobsters at OTN and FORCE receivers in Minas Passage during November-December 2017.

Table 3 Detection of acoustic tags at receivers in Minas Passage during 2017 and 2018 for movement of tagged lobsters. Tagging and reception sites are MB=Minas Basin, B=off Blomidon, P=off Parrsboro, MP=Minas Passage. Receivers were FORCE -E1, W1, D1, S2; OTN - 1-11; Study - M1-M6, M39-M34.

Tag #	Tagging Site	Reception Receiver and Month		
		MP 2017	MP 2018	Study MP 2018
984	MB	-	-	M34, June-July
986	P	3-S2, November	5-6-5-D1-4-3, July-August	-
989	P	-	3-2-3, May	-
991	MB	-	8, May	-
992	B	-	11, July	M39-M38-M37, June
	-	-		
995	MP	9, November	-	-
996	MP	-	-	M40, August
997	MB	-	-	M6, May-August
1003	MP	9, November	9-8-7, June-October	-
1004	MP	-	7, June	-
1007	MB	-	3, May	-
1009	P	-	7, May	-
1011	P	-	3, Apr-May	-
1012	P	-	3, May	-
1013	P	3-2-3-2, November-December	-	-
1014	P	-	11, August	-
1015	P	-	3-2-3, January-February	-
1018	MP	-	5-6-5, July-August	-
1019	MP	E1-W1, November	-	-
1027	MB	-	8, May	-
1028	MB	-	3, May	-
1030	P	1-3, May-4-3-4, August-November	M3-M5, May-June	
1031	P	-	3-3, April-May	M3, May

Acoustic tags # 982, 983, 999, 1000, 1001, 1002, 1008, 1020, 1021, 1022, 1023, 1024, 1025 were released in Minas Channel in Scots Bay, off Cape Split and off Halls Harbour but were not detected by Minas Passage receivers during the study.

were detected at the FORCE site at receiver D1. A total of 17 individual tagged lobsters were recorded at the OTN and FORCE receiver sites during January-November 2018. Acoustic tags recorded were 986, 989, 991, 992, 1003, 1004, 1009, 1011, 1012, 1014, 1015, 1018, 1027, 1028 and 1030 (Fig 13). Most lobsters passed a receiver during a short period (Table 3). Five lobsters remained near a receiver for extended periods.

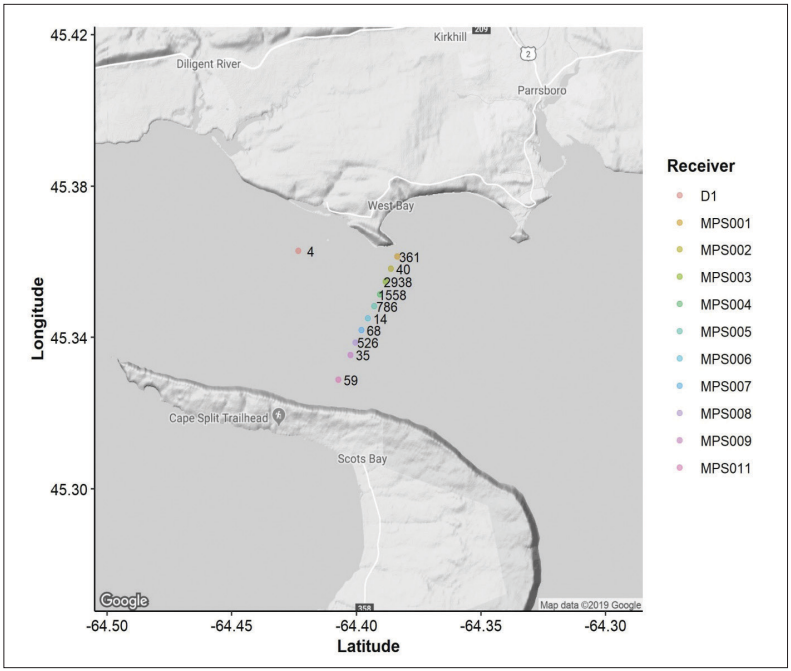


Fig 12 Total number of detections for acoustic tagged lobsters at OTN and FORCE receivers in Minas Passage during January-November 2018.

Receptions at the OTN line consisted of 15 female lobsters that had been berried when tagged and one male. Receptions at the FORCE site involved two females that were berried when tagged.

A total of 2241 acoustic pings from tagged lobsters were received at study receivers deployed from May-December 2018 on the north side of Minas Passage and a total of 1507 were detected at receivers deployed on the south side of Minas Passage during the same period (Fig 14). These included receptions at receivers M3, M5 and M6 on the north side and M34, M37, M38, M39 and M40 on the south side. A total of six individual acoustic tagged lobsters were detected at study receivers on the north and south sides of Minas Passage during May-August 2018 (Fig 15). Lobsters detected were 984, 992, 996, 997, 1030 and 1031 (Table 3). Detections included four female lobsters that were berried when tagged and two females were not berried when tagged. One lobster remained for an extended period near a receiver, the remainder for periods of a month or less.

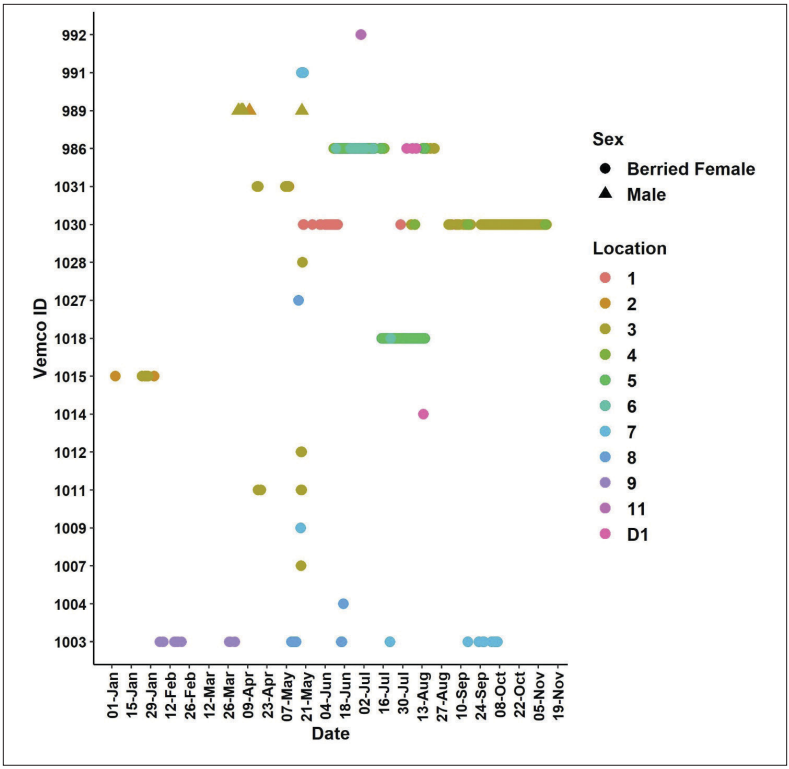


Fig 13 Receptions of individual acoustic tagged sexed lobsters at OTN and FORCE receivers in Minas Passage during January-November 2018.

Movement of American Lobster in Minas Basin, Minas Passage and the Bay of Fundy

Experimental trap deployments during August-October 2018 indicated there was a fluctuation in the abundance and sex ratio of adult lobsters in Minas Basin (Table 4). Lobster catch/trap was similar or only slightly less in Minas Basin traps than in Minas Passage during August (mean 12.4 vs 16.0) while during September into October catch/trap in Minas Basin declined to a mean of 7.7 lobsters while the catch/trap in Minas Passage increased to a mean of 20.1 by early September and remained high into late September (18.6) and early October (14.7). At the same time the proportion of females in the Minas Basin trap catches declined from a high of 37.0% in early August to 15.5% by mid-October while at the same time catch/trap increased in Minas Passage (42.2% to 52.2%, Table 4). Since the lobster fishery closed at the end of July,

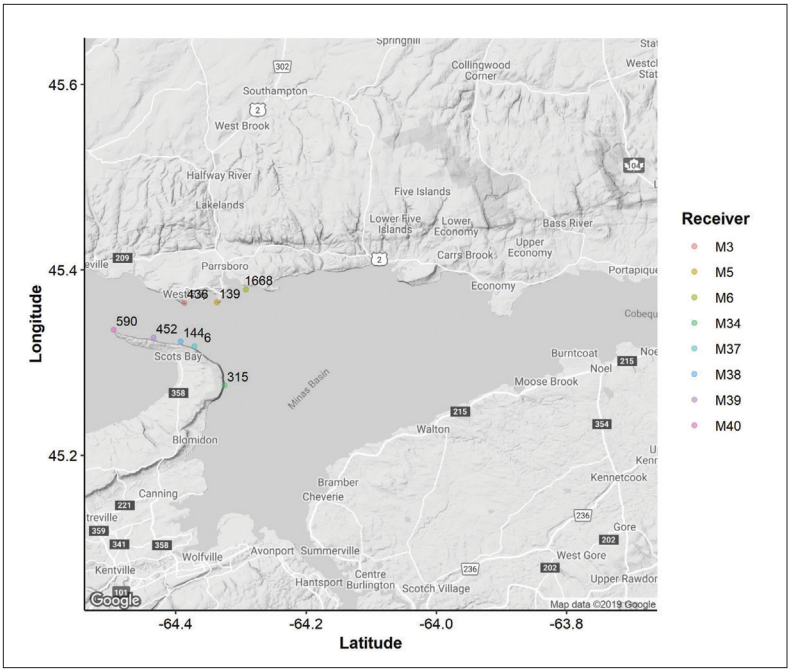


Fig 14 Total number for receptions of acoustic tagged lobsters at study receivers in Minas Passage and Minas Basin during April-December 2018.

Table 4 Catch/trap and % females for American lobster taken in experimental traps set in Minas Basin and Minas Passage during August 8-October 14, 2018.

	S Minas Basin		N Minas Basin		S Minas Passage		N Minas Passage	
Set Period	**Catch /Trap**	**% Female**	**Catch /Trap**	**% Female**	**Catch /Trap**	**% Female**	**Catch /Trap**	**% Female**
Aug 8 - Aug 14	12.6	34.5	12.3	38.7	19.6	49.6	12.5	41.8
Aug 27-Sept 4	11.2	30.2	11.1	24.2	25.1	42.6	15.1	37.6
Sep 15-Sep 24	6.7	22.4	8.2	23.5	20.8	40.9	16.4	42.2
Oct 6- Oct 14	6.6	13.7	9.3	17.4	16.3	40.9	13.1	52.2

and commercial catches would not have affected catch/trap, these data suggest there was a movement of predominately female lobsters out of Minas Basin and into Minas Passage during this period.

Movement of streamer tagged lobsters in Minas Basin and Minas Passage recaptured by lobster fishers during the period November 1-December 22, 2017, indicated that most short-term movement (mean

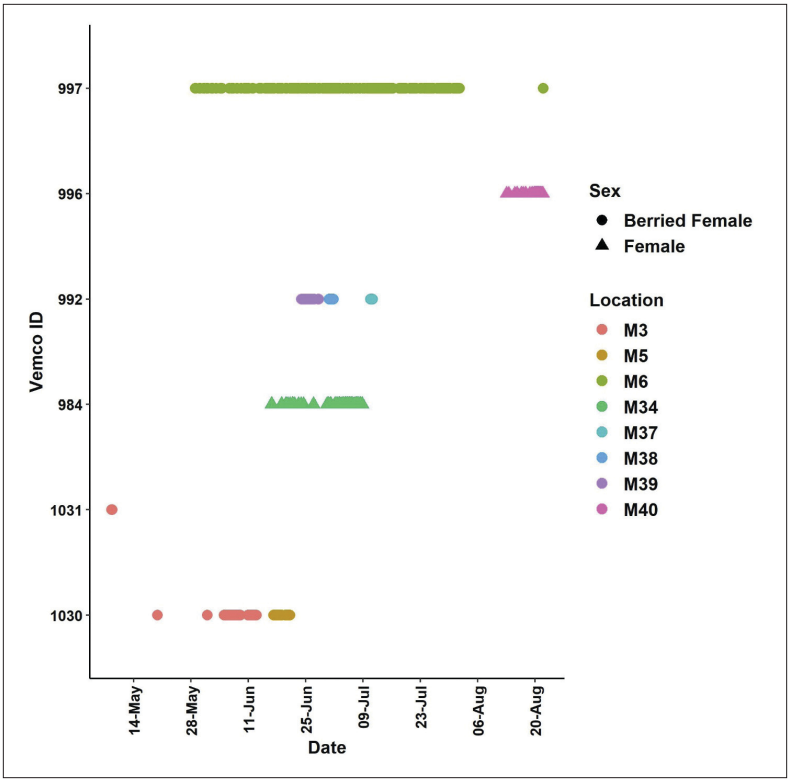


Fig 15 Receptions of individual acoustic tagged sexed lobsters at study receivers in Minas Passage and Minas Basin during May-August 2018.

distance 8.4 km) was also from Minas Basin towards Minas Passage (Fig 16). At the same time lobsters tagged in Minas Passage remained in the Passage. Lobsters tagged with streamers in Minas Channel (Scots Bay) during the same period also demonstrated short distance movement but from shallow to greater depths (Fig 16). Unfortunately tag returns ceased after fishers lifted their traps in late December 2017.

One streamer tagged lobster was captured during 2018 in our study traps (Lobster 1440). Lobster 1440 was tagged on the north side of Minas Passage on November 18, 2017, recaptured by a fisher 3 km away on November 27, 2017, and then captured in a study trap another 6 km away in West Bay on September 8, 2018. She was berried when tagged and when first recaptured but had released her larvae when captured again in September 2018.

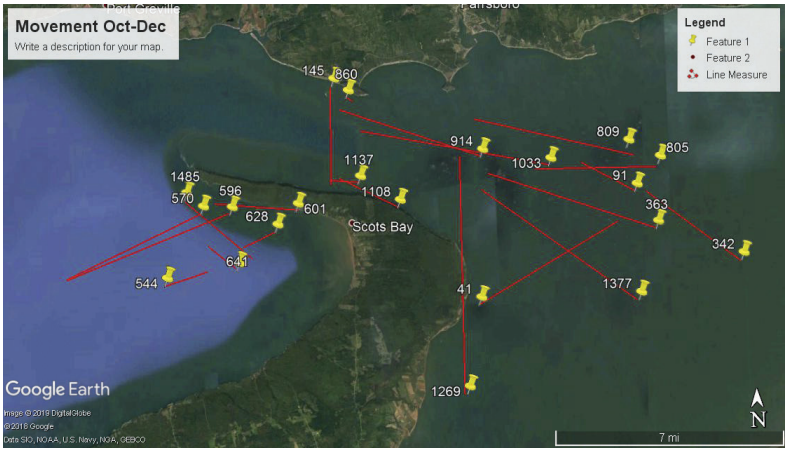


Fig 16 Movement of selected American lobster tagged with FLOY streamer tags during November-December 2017. Yellow symbols mark location of tagging in early November while numbers are the number on the tag. Tag returns ceased after fishers lifted their traps in late December.

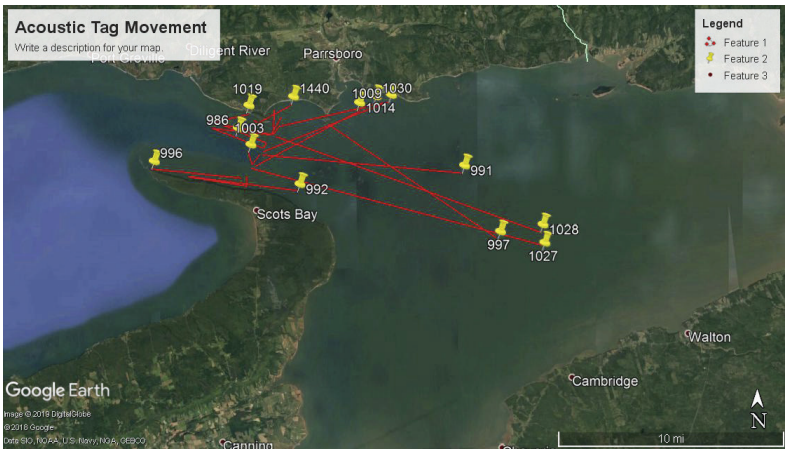


Fig 17 Movement of selected acoustic tagged lobsters in Minas Basin and Minas Passage. Yellow symbols mark the location of lobster tagging.

Lobsters marked with acoustic tags in Minas Basin during November moved from their tagging location into Minas Passage (mean distance 18.2 km; Fig 17) or were detected in the Passage during the following months (Fig 15). Those tagged in Minas Passage largely remained in the Passage or moved through the Passage later from unknown locations. Based on the high occurrence of receptions from deep-water locations

in the Passage this habitat appeared to be preferred by lobster. In addition, the most receptions were at the northern end of the OTN line (receivers 3, 4; Table 3).

Ten (58.8%) of the acoustic marked lobsters that were detected in the Passage were there for only a short period during May-June (Fig 15, Table 3). Their short period of detection and the fact all were berried females, suggests there may have been a return migration from the Bay of Fundy into Minas Basin during spring.

Six lobsters tagged on the north side of Minas Passage (Parrsboro) were only detected at the north side of the OTN line (Table 3) and two lobsters tagged on the south side of the Passage were only detected at the OTN line there (992, 996, Fig 17). Two acoustic tagged lobsters (1030, 1031) crossed from the north side of Minas Passage to the south side (Table 3). One streamer tagged lobster also moved from the north side to the south side of the Passage (Fig 16).

Streamer tags returned from commercial fishers after tagging during 2008 and 2017 demonstrated a proportion of the lobsters tagged in Minas Passage carried out long distance movements (>30 km) into the Bay of Fundy (Figs 18, 19). Most long-distance returns came after one year at large but a few lobsters moved long distances during short periods (Table 5). Lobsters L1043 and L1140 moved distances of 129 km and 106 km during June to November at estimated rates of 1.23 km/d and

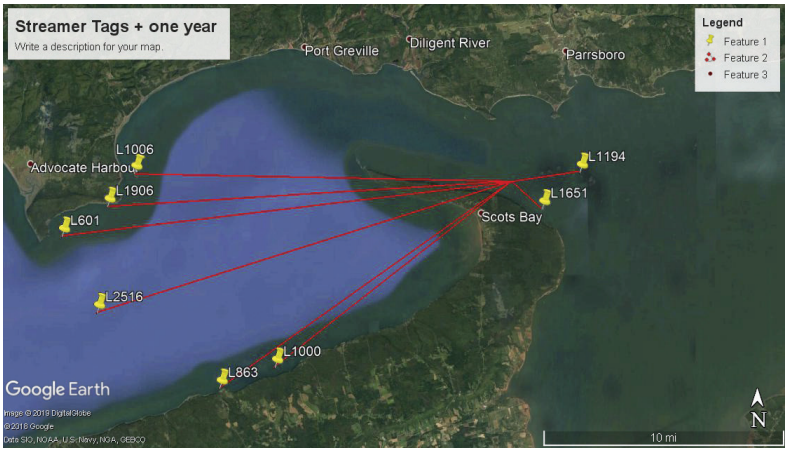


Fig 18 Movement after one year of American lobster tagged with FLOY streamer tags in Minas Passage during 2008. Yellow symbols mark the recapture point of each lobster.

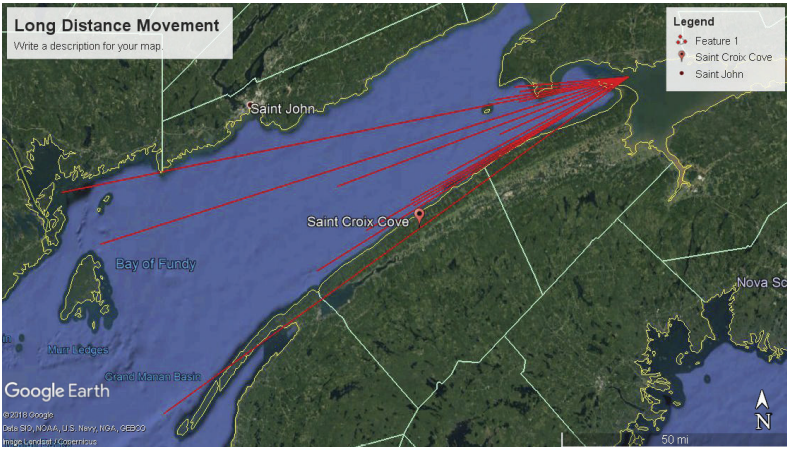


Fig 19 Long-distance movement of selected American lobster tagged with FLOY streamer tags during 2008 and 2017. Lobsters were tagged in the Minas Region (~45°20'30", 64 23'20") during the summer and fall commercial fishing seasons. Distances are straight line representations and do not represent the actual movement of individual lobsters.

1.0 km/d, respectively. Lobster 1194 moved 202 km to the lower BoF off Brier Island and lobsters MCG1424 and MCG1770 moved 195 km and 203 km, respectively, into the southwestern BoF over a period of one year (Table 5; Fig 19).

Lobsters that were streamer tagged in Minas Passage during 2008 and were recovered in the outer BoF were all smaller, immature individuals of 74-91 mm CL when tagged (Table 5). Four of five lobster's streamer tagged in Minas Passage during November-December 2017 and recovered in the BoF were mature females (118-140 CL mm) that had been berried when tagged. The fifth individual tagged in 2017 was again an immature female (85 CL mm).

DISCUSSION

The lobster fishery in the Minas region is a well defined stock that is largely fished in Minas Passage by a limited number of fishers (DFO 2021). Except for our short-term studies in the region during 2008 and 2011-2013, previous studies on population characteristics and movements in the BoF only sampled lobsters along the New Brunswick (NB) shore. All NB studies had similar results indicating that the BoF NB stock compared to other stocks in the Canadian Maritimes consisted

Table 5 **Long distance recapture locations of American lobsters in the Bay of Fundy marked with streamer tags in Minas Passage during 2008 and 2017. Distance is measured as a straight line (SLD) and probably does not represent the actual distance traveled during days at large.**

Tag Number	Date Tagged	Date Recaptured	Recapture Location	Lat	Long	SLD (km)	At large (d)
L0599	25/06/2008	11/10/2009	Isle Haute	45 16'49"	64 58'14"	47	471
L1043	08/07/2008	21/10/2008	off Digby Gut	44 45'09"	65 46'32"	129	105
L1119	12/07/2008	26/11/2009	off St. Croix Cove	44 57'04"	65 20'17"	88	347
L0890	23/07/2008	10/11/2008	off St. Croix Cove	44 58'06"	65 19'54"	86	107
L1052	28/07/2008	05/11/2008	off Port George	45 03'00"	65 11'12"	72	98
L1194	30/07/2008	15/11/2009	Lower Bay of Fundy	44 17'59"	66 27'32"	202	470
L1140	30/07/2008	15/11/2008	off Annapolis Royal	44 52'30"	65 33'02"	106	106
L2501	06/10/2008	21/07/2009	off Advocate	45 18'15"	64 51'35"	39	390
L2714	06/10/2008	28/10/2009	off Advocate	45 16'23"	64 52'50"	40	386
MCG0152	02/11/2017	25/11/2018	off Harbourville	45 10'17"	64 56'59"	49	387
MCG1119	18/11/2017	15/11/2018	mid Bay of Fundy	45 00'51"	65 40'64"	109	361
MCG1424	18/11/2017	24/11/2018	Owen Basin, NB	44 50'03"	66 44'09"	195	371
MCG1770	26/11/2017	20/11/2018	Deer Island, NB	44 59'50"	66 54'40"	203	358
MCG2690	22/12/2017	16/11/2018	off Advocate	45 19'12"	64 52'43"	40	391

of a high proportion of large lobsters, high levels of berried females (Campbell 1983, Robichaud and Lawton 1997) and some members of the population moved long distances (Campbell 1986, Campbell and Stasko 1986, Robichaud and Lawton 1997). We found similar biological characteristics and movements for the Minas region or the BoF Nova Scotia (NS) stock.

Population Characteristics

Minas region lobsters were characterized by a high proportion of large, adult lobsters. Mean size of lobster among 2017 samples were 101.7 and 121.0 mm CL for males and 102.5 and 115.7 mm CL for females. Maximum size attained in males was 200 mm CL and in females, 216 mm CL. Mean CL of berried females (124.1 mm) was significantly larger than the non-berried, female population (102.5 mm). Mean and maximum CL of Minas lobsters were similar to lobsters sampled along the NB BoF shore where mean CL was greater than 100 mm and maximum CL exceeded 180 mm (Robichaud and Lawton 1997) and both were greater than mean and maximum CL among lobster stocks sampled along the Atlantic shore of Nova Scotia (Dadswell 1979, Miller *et al*. 1987) or in the Gulf of St. Lawrence (Wilder 1963, Comeau and Savoie 2002), where mean and maximum lengths seldom exceeded 100 and 150 mm CL, respectively.

Sex ratio of lobsters in the Minas region was approximately equal numbers of males and females, similar to the proportional representation found in most other sampled populations (Cobb 1976, Goldstein *et al*. 2026). Male:female ratios found in Minas region samples were 1:1.2 during November-December and 1:0.6 during August-October. Such seasonal variation observed may have been caused by adult female movement to preferred overwintering locations (Campbell and Pezzack 1986).

The proportion of berried females in the Minas samples during late autumn (30-50%) was similar to lobster from the BoF NB stock sampled around Alma in Chignecto Bay during the same period, a region in the BoF with similar oceanographic characteristics to the Minas region (Campbell and Stasko 1986). In most other regions of the Canadian Maritimes concentrations of lobster with a high proportion of berried females are rare and the observed proportion of berried females in samples is low (<10%; Campbell and Robinson 1983, Campbell and Pezzack 1986).

Female lobsters in the Minas region began to extrude eggs during late September and early October. The proportion of berried females in the Minas region accounted for more than 30% in October-November and extrustion was complete by December when the berried female proportion of the population reached 50.4%. A proportion of 50% berried females in a sample is the highest possible situation since female lobsters only produce eggs every second year (Cobb 1976, Campbell 1983). Berried females were most abundant in Minas Passage during autumn and winter and this location is obviously extremely important to the life cycle of lobsters in the BoF NS stock. Choice of overwintering in this location is probably due to warmer temperatures in the Passage compared to Minas Basin. The threshold temperature of 3.4C^{o} for eggs to develop (Perkins 1972, Campbell and Stasko 1986) occurs there during most of the winter (Keyser *et al.* 2016).

The molt cycle of lobsters in the Minas region was opposite to the egg extrusion cycle (Cobb 1976). Hard-shelled lobsters accounted for 95-100% of lobster sampled from August to June. The Minas population molted during late-July when soft-shelled animals represented up to 42.9% in samples. By mid-August molting was complete.

Movement of Lobsters

Movement of lobsters in the Minas region demonstrated by seasonal sampling and marking with streamer and acoustic tags occurred over both short and long distances depending on season and time at large. Lobsters exhibited both short-distance movement in reponse to seasonal change (summer-winter) and long-distance movement possibly caused by life history requirements.

Based on the catch/trap and female proportion in catches, trap sampling on a two-week cycle in Minas region during August-October 2018 demonstrated a 10-30 km movement of predominately female lobsters from Minas Basin into Minas Passage. This seasonal movement between Minas Basin and Minas Passage was collaborated by both streamer and acoustic tagging. Lobsters marked by streamer tags in Minas Basin during 2017 moved up to 5-10 km towards Minas Passage during a six week period in November-December. Lobsters marked with acoustic tags demonstrated similar movement, traversing a distance of 5-20 km from Minas Basin into Minas Passage during November to December. Of the 125 acoustic tagged lobsters released in Minas Basin 3-11 km from Minas Passage during 2011-2012, 37 (29.6%) were detected in the Passage at either one of the two acoustic

receiver lines that were deployed or at the FORCE site. We also found that tagged lobsters were most commonly detected at the northern end of the OTN line and that they exhibited over-winter and long-term residence in the deepwater of Minas Passage. Time spent with lobster fishers demonstrated they knew this distribution of the lobsters well and concentrated their fishing effort in the northern, deeper area of the Passage (Dadswell, pers. obs.).

We found that acoustic tagged lobsters often moved past acoustic receiver arrays without being detected. During the acoustic study in 2011-2012, there were two receiver lines across Minas Passage east and west of the FORCE site. Numerous tagged lobsters that were released in Minas Basin were first logged at the FORCE site or the western most array proving they moved past the eastern OTN array without detection. During the 2017-2018 study lobsters tagged in November were often undetected in Minas Passage until May-June, but because of all the evidence for movement of lobsters into Minas Passage during late autumn we suggest that many passed the OTN line during November–December 2017 without being detected. Since the period of low current speed when acoustic tags would have been detected by the receivers occurs during an extremely narrow window in the Passage (Karsten 2008, Morrison *et al.* 2014) this possibility seems relatively plausible.

Trap sampling and tagging evidence lead us to propose that there may be an annual movement (migration) of lobster into and out of Minas Basin. The fact that a large proportion of the acoustically tagged lobsters observed moving through Minas Passage in MayJune were berried females (76.5%), and since the ratio of females to males in the Basin increased during this period to be highest during August suggests this migration exists. Whether the seasonal movement is related to egg release by females in the warmer water of Minas Basin or to obtain better foraging opportunities is yet to be proven.

Summer-winter movements of lobsters in the Canadian Maritimes have been well established in numerous studies. Campbell (1986) found that lobsters in the lower Bay of Fundy moved onshore to warmer water in summer and offshore to where warmer water occurred in winter and proposed that the movements were related to egg development. Similar seasonal movements have been described for tagged lobsters in the Gulf of St. Lawrence. Den Heyer *et al.* (2009) found that the distance of summer-winter lobster movement varied from 2.3-19.4 km depend-

ing on where the lobsters were tagged and the steepness of the bottom slope. Comeau and Savoie (2002) demonstrated a mean summer-winter movement distance of 12.3 km from shallow to deep water and back. Minas. In the Minas region such movement appears to be into Minas Passage for the winter, the closest winter warm area.

Long distance movement of lobsters from Minas region into the BoF was exhibited by lobsters marked with streamer tags both in 2008 and 2017. Movements of >30 km were demonstrated for both male and female immature lobster 70-90 mm CL and for large (110-140 mm CL) females that were berried when tagged. Some of the immature lobsters moved distances up to 100+ km during a period of four months (Minas Passage to Digby). Some large females moved distances up to 200 km over a period of approximately one year (Minas Passage to southern NS and the NB shore).

Long distance movement and migration, expecially by large females, has been well documented for BoF NB lobsters. Campbell (1986) and Campbell and Stasko (1986) demonstrated that female lobsters tagged off Grand Manan and off Alma in the inner BoF moved distances of 200-700 km into the Gulf of Maine. In contrast lobsters tagged on the outer coast of Nova Scotia and in the Gulf of St. Lawrence have never been found to move distances greater than 60 km (Miller *et al.* 1987, Comeau and Savoie 2002). It has been suggested that the Fundy long-distance movement is a result of the large tides and extensive drift of lobster larvae in the region (Quinn *et al*. 2017).

On the other hand, even with all the long distance movement demonstrated for the BoF NB lobster stock few tagged lobsters have been found to cross the BoF from the NB shore to the NS shore, a distance in most cases of only 40-70 km. Out of 647 tagged lobsters that had moved more than 100 km only 13 (2.0%) crossed the Bay from tagging sites at Grand Manan, Chance Harbour and Alma in NB (Campbell and Stasko 1986). Likewise, Robichaud and Lawton (1997) found that out of 100 tagged lobsters recovered, only 11 had crossed the Bay from NB to NS. In both studies lobsters predominately moved down the NB shore to the Gulf of Maine.

Long-distance tag returns from our study demonstrated similar regional movement. Lobsters tagged in the Minas region largely moved along the NS shore. Out of 26 tags recovered that had moved distances >30 km only two (7.6%) crossed the BoF to NB. We suggest that the lobster stocks on the two sides of the BoF are largely independent

due to egg release locations. Berried females from the BoF NB stock concentrate between Grand Manan and Alma, the BoF NS stock, in Minas Passage and Minas Basin.

This situation may have evolved over time because of the tidal, residual currents in the BoF (Bumpus and Lauzier 1965, Dadswell 1979). The residual current flows into the BoF along the NS shore and into Minas Basin before crossing the Bay to flow out along the NB shore. Females and their larvae released in the Minas Passage may be independent from females and their larvae released in Chignecto Bay creating two stocks, the BoF NS stock and the BoF NB stock.

Tidal Power Development and Lobsters

Tidal power development in Minas Passage has progressed slowly. An instream, propellor tidal turbine was deployed in the Passage during 2009 (AECOM 2009) and another design of the same turbine type in 2017 and 2018 (Cape Sharp Tidal 2018). Both turbines broke down after deployment periods of only a few weeks.

Propellor turbines are known to cause mortality to organisms because of mechanical strike, pressure flux, shear, and cavitation in the turbine draft tube (Dadswell and Rulifson 1994; Bangley *et al.* 2022). Since the instream propellor turbine designs are raised above the substrate (FORCE 2017) it is unlikely there will be much interaction between these turbines and benthic organisms such as lobsters. Lobster larvae, however, are pelagic and can remain in the pelagic zone for periods up to two months (Scarratt 1973, Goldstein *et al.* 2026). Since larvae have a discrete size (~1-20 mm) there is a potential level of interaction between the spinning blades of a propellor turbine and larvae. Although the calculated level of interaction is low (<1%) there will be some degree of mortality because instream turbines operate during all periods of tidal flow and an immense volume of water containing larvae will pass through the turbine (FORCE 2017). It is also known that lobster larvae are very sensitive to pressure change (Ennis 1975). Whether or not pressure flux in the propellor turbine draft tube will have deliterious effects on lobster larvae is unknown.

It is uncertain what future plans there are for tidal hydro-kinetic deployment in Minas Passage and/or what sort of devices will be deployed (Big Moon Power 2018, Bangley *et al.* 2022). Since the BoF NS lobster stock utilizes Minas Passage extensively, it may be unwise to deploy types of instream tidal turbines in this region that might

impact the lobster population. All future studies on deployment of various types of tidal turbines in Minas Passage should include studies of their potential impact on American lobsters.

Acknowlegements We thank lobster fishers Mark Taylor, Gerry Taylor, Scott Woolaver and Bobby Vaughan for contributing their time, vessels and gear to assist in this research. We thank Hunter Porter, Kaycee Morrison, Jeremy Broome, and Angelica Lockhart-Bastien for assisting with the field sampling of lobsters and the Mi'kmaw Conservation Group for providing the streamer tags in 2017 and accepting tag return information on their website. Thank you Perry Comolli for helping produce the maps. Funding for our studies was provided by Big Moon Power Canada, Fundy Ocean Research Center for Energy, Acadia University, the Mi'kmaw Conservation Group, and the Natural Sciences and Engineering Research Council of Canada grant to Anna Redden.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 523-549

THE RAPID SPREAD OF INVASIVE SMALLMOUTH BASS AND CHAIN PICKEREL AND A CHANGING NOVA SCOTIA FISHERY

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ABSTRACT

In the 1940s, Smallmouth Bass (*Micropterus dolomieu*) and Chain Pickerel (*Esox niger*) were confirmed in 14 lakes collectively in southwest Nova Scotia. By 2025, Smallmouth Bass had been documented in 340 lakes, while Chain Pickerel had been reported in 180 lakes, representing approximately 34% of the province's lentic habitats. The initial spread of Smallmouth Bass was facilitated by government-sanctioned stocking; however, over the past 80 years, the range of both species has expanded due to natural migration and illegal introductions. The increasing popularity of Smallmouth Bass and Chain Pickerel among anglers is reflected in annual catch statistics. While the spread of these invasive species has created additional angling opportunities, their introduction has significantly disrupted the natural integrity of freshwater ecosystems, permanently altering the landscape of the sport fishery. In response to this challenge, a range of strategies and policy changes have been implemented to address the expanding threat posed by aquatic invasive species.

Keywords: brook trout, aquatic invasive species, fisheries management, rotenone

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INTRODUCTION

The global proliferation of invasive species poses significant threats to ecosystems, resulting in extirpation and even extinction of native species (Wind 2004). Freshwater ecosystems are particularly vulnerable to invasions arising from anthropogenic introductions due to geographical isolation created by watershed boundaries, which prevent native aquatic species from dispersing into unimpacted habitat away from invasive species they are unequipped to compete with (Dextrase and Mandrak 2006). The ecological impacts of such introductions are significant, often leading to permanent shifts in aquatic ecosystems that disrupt food webs and escalate competition and predation pressures on native species, including fish, zooplankton, macroinvertebrates, amphibians, and reptiles (Jackson 1995). Once invasive species become established, they can act as source populations for further introductions and spread (Wind 2004).

Unauthorized introductions of Aquatic Invasive Species (AIS) can arise from various sources, including aquaculture escapees, transfers and releases from the aquarium trade, and introductions incentivized for recreational angling (Benson 1999, Naylor *et al.* 2001, Kerr 2014, Gertzen *et al.* 2017). Anglers are recognized as significant contributors to the spread of AIS through intentional acts, such as illegal introductions aimed at developing additional angling opportunities (Rahel 2004); careless practices, like the improper disposal of bait containing eggs and/or juveniles from non-native species; and unintentional transport on boats and boat trailers that are not properly cleaned, drained, or dried (Kerr 2014). Following the introduction, the successful establishment of invasive species is often contingent upon specific ecological factors, including native fish community composition and water quality (Kolar and Lodge 2002, Sharma *et al.* 2009).

Nova Scotia's freshwater systems are characterized by their limited size and species diversity relative to other regions in continental North America and are highly susceptible to AIS (Alexander *et al.* 1986, Davis and Brown 1996). Native fish communities in Nova Scotia are comprised of freshwater species and an array of diadromous species (Alexander *et al.* 1986) with the anadromous Brook Trout (*Salvelinus fontinalis*; BT) designated as the provincial fish. The province features over 6,700 lakes and 64 main river systems fed by many small streams (Davis and Brown 1996). These freshwater habitats are shaped by two

main geological regions: the southern uplands, characterized by the metamorphic rock and shallow soils of the southwest Nova Scotia, which support acidic surface waters with limited productivity, and the sedimentary surficial geology in northeastern Nova Scotia, including Annapolis Valley, that fosters higher freshwater productivity (Davis and Brown 1996). Additionally, surface waters in the southern regions of the province are warmer, exerting seasonal stress on cold-water salmonids like BT compared to cooler northeastern areas (MacMillan *et al.* 2005).

As piscivores, both Smallmouth Bass (*Micropterus dolomieu*; SMB) and Chain Pickerel (*Esox niger*; CP) can consume a wide array of large prey species, including fish, frogs, salamanders, turtles, snakes, mice, and young waterfowl (Mitchell *et al.* 2010, Sanderson *et al.* 2009, Whittier *et al.* 1997). Their introduction can result in competition with native piscivores and the extirpation of smaller-bodied fish species (Brown *et al.* 2009, Mitchell *et al.* 2010, Loppnow *et al.* 2013). Both SMB and CP were established in southwest Nova Scotia in the 1940s, the former through government introductions and the latter through illegal introductions (McNeill 1996, LeBlanc 2010, Mitchell *et al.* 2010).

The spread of SMB outside their native range in Ontario is anticipated to lead to the extirpation of leuciscid populations and a loss of aquatic biodiversity, culminating in the homogenization of aquatic fauna (Jackson and Mandrak 2002). Native species may exhibit avoidance behaviour in response to introduced SMB, potentially increasing their predation risk and depleting energy reserves during foraging activities (Schlosser 1987). Native salmonids, including BT, are particularly vulnerable to the impacts of introduced SMB through direct predation on juvenile life stages and changes in food web dynamics (Vander Zanden *et al.* 1999, Harvey and Karieva 2005, Fritts and Pearsons 2006, Sharma *et al.* 2009a).

Similarly, the introduction of CP has been shown to result in detrimental impacts to species richness and diversity (Whittier *et al.* 1997). In Nova Scotia, the introduction of CP has adversely affected native fish populations. Mitchell *et al.* (2010) compared lakes with and without CP and found those with CP showed diminished species richness and diversity, truncated size distributions, and simplified food webs. Risk assessments of closely related Northern Pike (*Esox lucius)* have similarly demonstrated catastrophic effects on native fish communities post-introduction (DFO 2010).

Both SMB and CP thrive in lentic habitats, deep pools and slow-flowing sections of river systems (Chaput and Caissie 2010). Established populations of these two invasive species are prevalent in southwest Nova Scotia. Water temperature is a key factor influencing the distribution of SMB and other freshwater fish species (Armour 1993). Juvenile SMB, particularly those under 50 mm, struggle to survive the winter in New Brunswick lakes due to the cold climate (Curry *et al.* 2005). However, the presence of SMB and CP in northeastern Nova Scotia suggests that the cooler conditions do not inherently impede the establishment of these populations, and projected warming trends could further expand habitat suitability for these AIS (Shuter *et al.* 2002).

Despite limited research on the impact of invasive species on BT in Nova Scotia, lake survey datasets can offer valuable insights. Peterson and Martin-Robichaud (1989) note the absence of BT in lakes inhabited by SMB and CP, both in Nova Scotia and New Brunswick. Similarly, risk evaluations of SMB in Nova Scotia and New Brunswick have ranked the potential impact of SMB on lake habitats as high, and on riverine habitats as moderate, concluding that SMB can become dominant within the aquatic food webs of both habitat types (Chaput and Caissie 2010).

Anecdotal evidence from Nova Scotian anglers indicates a decline in trout catches following SMB introductions, a trend corroborated by existing literature and documented in other regions (Oliver *et al.* 1991, Whittier and Kincaid 1999, Brown *et al.* 2009). Recent shifts in species distribution, coupled with increasing popularity among anglers, have enabled SMB to carve out a substantial presence within Nova Scotia's sport fishery. These changes reflect the species' adaptability and in combination with evolving angler preferences highlight the importance of adaptable resource management strategies that meet the needs of current sport fishing trends in the province.

The growth of SMB and CP fisheries in Nova Scotia from the 1940s to the 1990s resulted in the establishment of popular recreational fishing opportunities, subsequently prompting SMB angler groups to advocate for greater fishing access and protective regulatory initiatives. Consequently, management strategies evolved to promote these fisheries, including policies that support competitive sport fishing events, regulations that increased opportunities, such as extended seasons and night fishing, and conservation measures such as spawning season restrictions to reduce fish harvest.

However, in response to the continued proliferation of AIS throughout the province, management strategies have more recently shifted towards a stricter regulatory approach aimed at curtailing the spread and mitigating the rate of introductions. Typically, public awareness campaigns and legislative measures are the first step in this regard, as eradicating established invasive fish populations is both costly and complex (Rahel 2004). Management measures to control the spread of invasive species often occur decades after their initial introduction, which frequently necessitates a review of policies initially intended to protect and promote these species (Rahel 2004).

REVIEW

This review summarizes the expansion of SMB and CP distribution since their first introduction to Nova Scotia, incorporating historical datasets that describe the spread of these AIS within the province. We also summarize angler catch data for native BT and AIS from the 1980s onwards, identifying major trends within the federal Survey of Recreational Fishing in Canada and the provincial Nova Scotia Angler Licence Stub Program. Finally, we examine fisheries management strategies employed for AIS from the 1990s onwards, creating a timeline of recreational fishing regulations related to these two species, with emphasis on more recent approaches to control their spread and mitigate ecological impacts.

Evaluating AIS Distribution

Reports on the distribution of invasive SMB and CP in Nova Scotia are frequently submitted by anglers and the public to the Nova Scotia Department of Fisheries and Aquaculture (NSDFA). These reports require confirmation from NSDFA staff or other knowledgeable individuals (e.g. community groups or other government partners). Confirmation surveys employing angling, electrofishing, and eDNA are also conducted to verify the presence of invasive species in new waterbodies. Once reports are deemed accurate, they are added to a provincially maintained list of waterbodies impacted by AIS.

To quantify the spread of invasive SMB and CP across primary and secondary watersheds in Nova Scotia, we calculated the surface area of lentic habitat impacted by AIS across the province. It is important to note that the date of detection does not necessarily reflect

the introduction date, but rather the 'confirmation' date, as species confirmation often occurs several years post-introduction. Additionally, all totals are conservative estimates based on available data. For example, remote systems that are connected to impacted waterbodies may be inaccessible, but in the absence of barriers, can be assumed to host AIS. For the analysis of AIS distribution data, the number of confirmed AIS waterbodies was summarized by decade. They exclude riverine habitat, given the nature of the dataset and challenges associated with quantifying total suitable lotic habitat. We evaluated the number of primary and secondary watersheds occupied by AIS, the percentage of lentic ecosystem surface area affected, and the number of lakes impacted by SMB and CP using the provincial AIS detection database, the Nova Scotia Hydrographic Network, and the Nova Scotia Topographic Database (UTM/NAD83 projection). This analysis also utilized provincial watershed mapping information captured using QGIS software. The total percentage of lake habitat occupied by SMB and CP was calculated based on a total lake surface area of 225,495 hectares within Nova Scotia, as described by Alexander *et al.* (1986).

History of AIS Introductions

In response to rising concerns over degrading habitat suitability for native salmonids in southwestern Nova Scotia, the provincial government introduced SMB to Bunker Lake, Yarmouth County, in 1942 with the intention of enhancing angling opportunities for alternative species. This lake, in addition to nine others, was seeded through government-sanctioned SMB stocking, although only six of these lakes produced self-sustaining populations by 1953 (McNeill 1995). In contrast, the introduction of CP to Nova Scotia was unauthorized, with illegal introductions to three lakes in the southwestern region, which were first detected in 1945 (Catt 1949). The Spectacle Lake system in Digby County was the first system where CP was officially confirmed in Nova Scotia (Gilhen 1974).

By 1960, the distribution of SMB and CP had expanded to 14 and seven waterbodies, respectively. Throughout the 1960s and 1970s, clusters of SMB-inhabited waterbodies emerged near the city of Halifax along the eastern shore of the province and in Kings County. In 1971, government-sanctioned stocking of SMB in Spectacle Lake, Digby County, resulted in the establishment of a self-sustaining population alongside already established CP (McNeill 1995). From 1967 to 1984, five lakes within a hydroelectric development system known as the

Gaspereau-Black River Complex were stocked to further enhance angling opportunities (McNeill 1995). Murphy Lake, Kings County, was the final lake in the system to be stocked, with releases recorded in 1984. This event concluded all historical government-sanctioned SMB stocking in the province (McNeill 1995, LeBlanc 2010).

By 2000, the total number of lakes across the province with SMB and CP had expanded to 132 and 84, respectively, including the first confirmation of their presence in northern mainland Nova Scotia. From 2000 to 2019, impacted lakes increased to 295 and 165, respectively. Recent expansion into un-colonized northeastern mainland watersheds occurred in 2019 with SMB in Piper Lake, St. Mary's River system and again in 2020 with Dobsons Lake, Cole Harbour River system. However, successful eradication of SMB from Piper and Dobsons Lakes was achieved using Noxfish Fish Toxicant II (5% rotenone) in 2020 and 2022, respectively (Fig 1). These two systems remain free of SMB and CP at present.

By 2025, a total of 441 lakes and approximately 45.8% of the secondary watersheds in the province were inhabited by either SMB, CP or both. Lakes with confirmed AIS account for approximately 6.6% of the total 6674 lakes in the province (Alexander *et al*. 1986). However, the lakes where AIS are introduced, and therefore those with confirmed AIS presence, are often larger lakes. Of the total lentic habitat in the province, 75,703 hectares are occupied by AIS, representing 34% of the province's total lentic surface area (Table 1). Of this, lakes with SMB only (n=261) account for 3.9%, lakes with CP only (n=101) account for 1.5%, and lakes with both SMB and CP (n=79) account for 1.2%.

Table 1 Breakdown of lake count and total lake surface area of CP and SMB occupied lakes in Nova Scotia by decade from 1942-2025.

Decade	CP Lake Count	SMB Lake Count	CP and SMB Lake Count	Surface Area of CP Lakes (ha)	Surface Area of SMB Lakes (ha)	% of Lentic Habitat with SMB and/or CP	% of Total Lakes with SMB and/or CP
1940's	7	7	0	423	427	0.4%	0.2%
1950's	7	14	0	423	1019	0.6%	0.3%
1960's	17	30	1	835	6962	3.4%	0.7%
1970's	29	51	6	1754	9004	4.6%	1.3%
1980's	32	75	6	1896	14726	7.2%	1.7%
1990's	74	144	23	9376	25576	12.8%	3.6%
2000's	104	227	45	14715	45470	21.6%	5.6%
2010's	152	308	73	38408	52413	31.6%	8.0%
2025	180	340	79	41568	55352	33.6%	9.0%

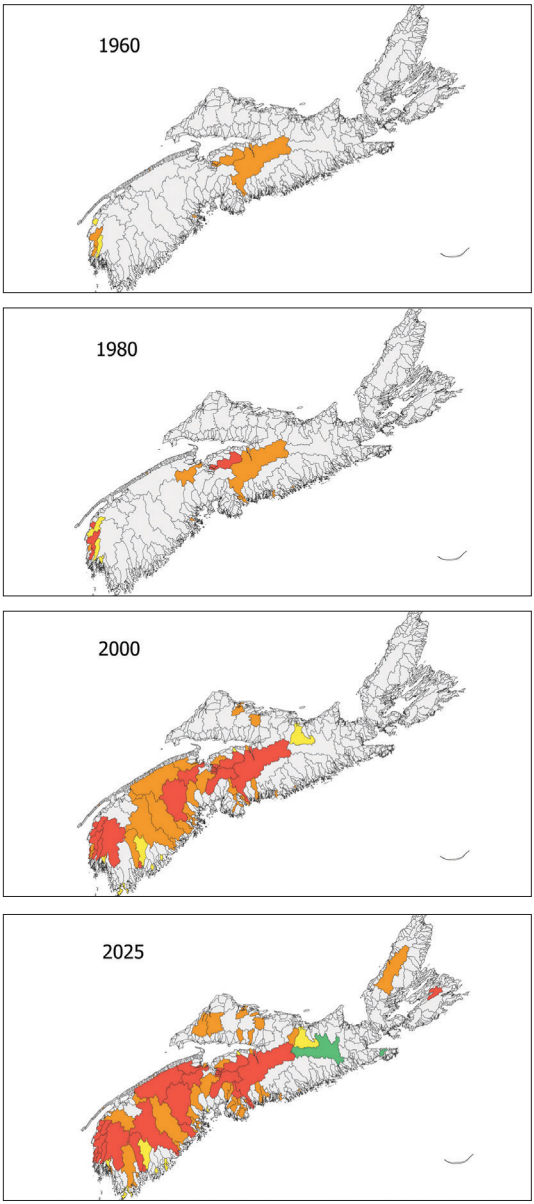


Fig 1 **Changes in distribution of CP and SMB across secondary watersheds from 1960 to 2025. Orange represents SMB presence, yellow represents CP presence, red represents presence of both SMB and CP, and green represents the watersheds of the two lakes (Piper Lake, St. Mary's River and Dobsons Lake, Cole Harbour River) where eradication efforts (rotenone) have taken place.**

Monitoring changes in species distribution has been significantly enhanced through the adoption of eDNA assessments (Baillie *et al.* 2019, Loeza-Quintana *et al.* 2019). These tools facilitate the rapid detection of invasive species and have proven effective in global contexts, including monitoring problematic species such as Asian Carp and Round Goby (Jerde *et al.* 2013, Nevers *et al.* 2018). In Nova Scotia, eDNA surveys have been employed to track the distribution of SMB and CP in key areas such as Kejimkujik National Park (Loeza-Quintana *et al.* 2021) and NSDFA initiatives in St Mary's River (Piper Lake) and Cole Harbour River (Dobsons Lake). Department of Fisheries and Oceans Canada's AIS program has adopted widespread provincial eDNA monitoring through community partnerships with Nova Scotia Invasive Species Council, Atlantic Salmon Federation, Nova Scotia Salmon Association, and Margaree Salmon Association, among others. These groups share novel observations of SMB and CP detected through their work. The increasing popularity of eDNA within the province complements traditional sampling methods for AIS surveillance and allows managers to more accurately track the distribution of SMB and CP.

Angler Catch

Trends in annual angler catch data serve as an index for assessing the health of fisheries and as a means of understanding angler preferences. Catch data for this study were collected from two primary sources: 1) the Survey of Recreational Fishing in Canada (SRFC), and 2) the Nova Scotia Angler Licence Stub Program (ALSP). The SRFC, conducted every five years, gathered data from a randomized sub-sample of licensed anglers. This comprehensive survey provides critical insights into recreational harvests, fishing activities, and economic statistics reported by anglers across Canada. For our analysis, we utilized Nova Scotia provincial catch data from the SRFC covering the years 1980 to 2015 (see DFO 1988-2019 for survey methodology). The SRFC was discontinued following the 2015 survey.

The Nova Scotia ALSP, initiated in 1966, is associated with the purchase of a recreational fishing licence and collects individual angler catch data across various species. A pre-addressed and postage-paid stub is attached to each fishing licence sold within the province. Online licence holders (available from 2020 onwards) also receive a link for their digital report card. Each angler is required to report annual effort (days fished) and catch by species in the respective counties they fished.

Catch data are subsequently submitted to the NSDFA. These data are used to estimate the total annual catch by extrapolating the proportion of angler-submitted licence stubs to the total number of licences sold each year. Reliability of these estimates may be compromised by varying/low return rates and the sample's non-random nature. Despite these limitations, catch trends reflect changes in angler preferences, fishing opportunities, and the health of the fishery. To account for variations in fishing effort, we standardized the total catch data from the ALSP dataset by converting it to annual catch per angler (CPA) for BT, SMB, and CP.

The CPA from SRFC and the ALSP indicate decreasing BT catches over time with concurrent increases in SMB and CP catches (Fig 2). The change in CPA for BT and SMB is greater in 2015 relative to other survey years for the SRFC, while the ALSP remains more consistent for BT across time and increases for SMB in 2015. Over the 35-year period, licence sales decreased from a high of over 82,000 to a low of almost 50,000 (Table 2). While reporting catch data is mandatory, response rates for the ALSP range from 3.4 to 7.3 %, which presents a challenge for managers trying to get an accurate representation of changes in the fishery through time.

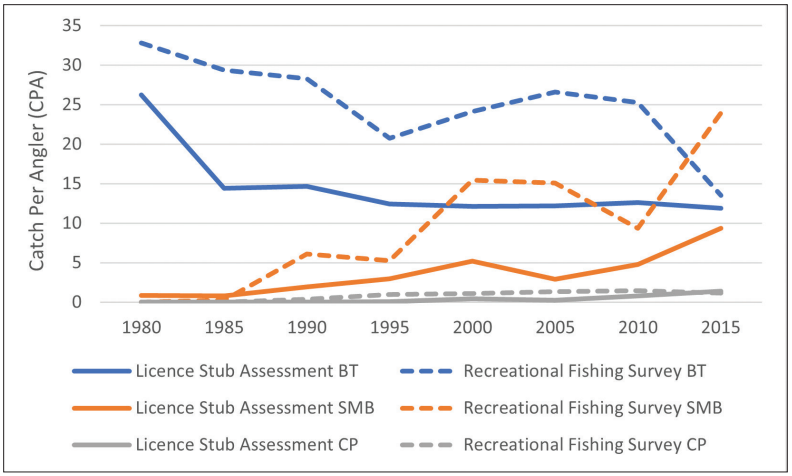


Fig 2 **Catch Per Angler (CPA) for SMB, CP and BT from the Nova Scotia Angler Licence Stub Program and the National Sportfishing survey data for 1980-2015, Nova Scotia.**

Table 2 **Licence sale statistics, total catch and catch per angler (CPA) of Brook Trout, Smallmouth Bass, and Chain Pickerel from the Nova Scotia Angler Licence Stub Program and the National Sportfishing survey 1980-2015, Nova Scotia.**

	1980	1985	1990	1995	2000	2005	2010	2015
Licence Stub Assessment								
Licence sales (stubs)	82,449	78,095	68,276	62,481	64,217	50,050	65,206	57,841
Stubs returned %	3.4	7.3	7.1	7.2	5.4	3.0	4.7	3.5
Brook Trout	2,164,109	1,126,229	1,000,948	775,945	776,850	609,504	823,909	686,410
Smallmouth Bass	71,907	64,334	133,320	185,726	333,317	145,847	311,041	541,376
Chain Pickerel	na	na	na	4,411	26,187	11,188	51,110	81,373
Brook Trout CPA	26.2	14.4	14.7	12.4	12.1	12.2	12.6	11.9
Smallmouth CPA	0.87	0.82	2.0	3.0	5.2	2.9	4.8	9.4
Chain Pickerel CPA	na	na	na	0.07	0.41	0.22	0.78	1.41
Survey of Recreational Fishing in Canada								
Brook Trout	2,712,503	2,295,695	2,035,523	1,324,900	1,560,416	1,351,559	1,621,807	777,123
Smallmouth Bass	na	18,007	439,073	337,061	998,487	766,977	598,869	1,378,344
Chain Pickerel	na	1,092	26,388	63,892	68,879	67,450	94,769	65,031
Brook Trout CPA	32.8	29.4	28.3	20.8	24.1	26.6	25.3	13.5
Smallmouth CPA	na	0.23	6.1	5.3	15.5	15.1	9.3	23.9
Chain Pickerel CPA	na	0.01	0.37	1.0	1.1	1.3	1.5	1.1

Fisheries Management

SMB Regulation Changes

Changes to SMB angling regulations over the past 25 years (2000 to 2025) are summarized in Table 3. Between 2000 and 2001, growing interest in improving the SMB fishery within the angling community garnered support for the use of special regulations on specific waterbodies, to protect larger individuals and thin out high-density, slow-growing populations. Special SMB Management Areas (SBMAs) were created on targeted lakes, and fisheries were classified into categories such as high-harvest fisheries (HHF) and trophy fisheries (TF) (NSDFA 2001). HHFs encouraged exploitation with a large daily bag limit of ten fish, while TFs incorporated various measures to reduce harvest, such as reduced bag limits of three fish and size regulations aimed at safeguarding larger fish. Notably, the season in SBMAs was extended from Oct 31-Dec 31. Province-wide SMB spawning season (SS) specific regulations were also introduced in 2001, which included mandatory release and bait restrictions during spawning times in late spring, except in HHFs. SS bait restrictions remained in place until 2008 (NSDFA 2008). Additionally, in 2001, night fishing opportunities for SMB were introduced in select waterbodies near Halifax.

By 2010, angler's concerns about AIS were being strongly expressed in the Recreation Fishing Survey data. For the first time since the initial survey in 1975, control of AIS was rated as the number one concern for anglers. However, according to the 2010 survey data, 98% of SMB and 94% of CP caught were still being released back into their habitats (NSDFA 2012b). This highlights the complexity of fisheries management and of developing strategies that promote or mandate retention of these AIS within the angling community. In 2011, NSDFA further differentiated their management approaches between the NE and SW regions of the province. In the SW region, SMB continued to be managed as sportfish with regulations remaining largely unaffected. In the NE region, they were managed as an invasive species, and SMB seasons were closed (with some exceptions) to further discourage illegal introductions. Where SMB angling was still permitted, the bag limit increased to 25 in most lakes to encourage removals (NSDFA 2011). In November 2012, the Live Fish Possession Regulations created under the Fisheries and Coastal Resources Act came into effect and then were first included in the Anglers Handbook

Table 3 **Summary of angling regulations related to Smallmouth Bass (SMB) in Nova Scotia from 2000-2025. The table is divided into the two managment regions of the province; the southwest (SW) region and the northeast (NE) region. Regulations have differed between the two regions since prior to 2000. Special Bass Management Areas (SBMA), including High Harvest Fisheries (HHF) and Trophy Fisheries (TF) are referenced throughout, as are specific SMB spawning season (SS) regulations. Season and bag limit changes are bolded for added clarity on when changes occurred.**

Year(s)	SW Region Season (Bag limit)	NE Region Season (Bag limit)	SBMAs & SSs Season (Bag limit)	Description of regulation change(s) and additional notes
2000	Apr 15-Oct 31 (5)	Apr 15-Sep 30 (5)	N/A	
2001	**Apr 1**-Oct 31 (5)	**Apr 1**-Sep 30 (5)	**HHF: Apr 1-Dec 31 (10)** **TF: Apr 1-Dec 31 (3)** **SS: Apr 21-Jun 10 (0)**	SBMA established. HHF - bag limit 10 with two over 25 cm, TF - bag limit 3 with one over 40 cm, all between 30-40 cm released. SS - zero retention, no natural bait permitted in all waters except in HHFs. Night fishing for SMB permitted on several waterbodies.
2003, 2004	Apr 1-Oct 31 (5)	Apr 1-Sep 30 (5) **Extended season lakes:** **Apr 1-Oct 31 (5)**	HHF: Apr 1-**Oct 31**/ Dec 31 (10) TF: Apr 1-Dec 31 (3) SS: **Apr 17-Jun 6** (0)	One new HHF lake established in Cape Breton, Inverness Co. (Apr 1-Oct 31). Five SMB new lakes in Pictou Co., Cumberland & Colchester Co.'s with extended seasons (Oct 31). Increased SMB angling opportunities established.
2008	Apr 1-Oct 31 (5)	Apr 1-Sep 30 (5) Extended season lakes: Apr 1-Oct 31 (5)	HHF: Apr 1-Oct 31/ Dec 31 (10) TF: Apr 1-Dec 31 (3) SS: **Apr 1-Jun 15 or Jun 30** (0)	Province-wide natural bait prohibition during SS removed. HHF - max length changed to 30cm. TF - all fish over 35 cm to be released. A number of new lakes added to the HHF and TF lists. SS dates were earlier in SW regions.

Table 3 cont'd.

Year(s)	SW Region **Season (Bag limit)**	NE Region **Season (Bag limit)**	SBMAs & SSs **Season (Bag limit)**	**Description of regulation change(s) and additional notes**
2011	Apr 1-Oct 31 (5, **25 Hants Co.)**	**Closed all year.** **Some exceptions: Apr 1-Oct 31 (25)**	TF: Apr 1-Dec 31 (3) SS: Apr 1-Jun 15 or Jun 30 (0)	HHF regulations removed. No open season in NE region except for select lakes where the bag limit was increased to 25. Three more TF locations established in Queens and Colchester Co.'s.
2013	Apr 1-Oct 31 (5, 25 Hants Co.)	Closed all year. Some exceptions: Apr 1-Oct 31 (25)	TF: Apr 1-Dec 31 (3) SS **(within SBMAs only): May 1-Jun 15** (0)	SS restrictions dropped outside SBMAs. Live Fish Possession Regulations created under the Fisheries and Coastal Resources Act came into effect late 2012 (Nov), and first included in the Anglers Handbook in 2013.
2014, 2015	Apr 1-Oct 31 (5, 25 Hants Co.)	Closed all year. Some exceptions: Apr 1-Oct 31 (25)	TF: Apr 1-Dec 31 (3) SS (SBMAs): **May 1- Jun 15** (0)	Four new SMBA lakes established in SW region. Middle River, Pictou added to lake exceptions open for SMB.
2017, 2018	Apr 1-Oct 31 (5, 25 Hants Co.) **Extended season lakes: Apr 1-Dec 31 (3)**	Closed all year. Some exceptions: Apr 1-Oct 31 (25)	Apr 1-Dec 31 (3) SS (SBMAs): May 1-Jun 15 (0)	Dropped the term 'Trophy Fisheries' within SBMAs (2017). Extended seasons (Apr 1-Dec 31) designated for eight new lakes in SW region (2018).
2019	Apr 1-Oct 31 (5, 25 Hants Co.) Extended season lakes: Apr 1-Dec 31 (3)	Closed all year. Some exceptions: Apr 1-Oct 31 (25)	Apr 1-Dec 31 (3) SS (SBMAs): May 1- Jun 15 (0)	Piper Lake (Pictou Co.) closed to all angling for all species due to detection of SMB, the first confirmation in this watershed.

2020	Apr 1-Oct 31 (5, 25 Hants Co.) Extended season lakes: Apr 1-Dec 31 (3)	Closed all year. Some exceptions: Apr 1-**Sep 30** (25)	Apr 1-Dec 31 (3) SS (SBMAs): May 1-Jun 15 (0)	The provincial SMB managment boundary was adjusted slightly and decribed in detail for the first time in Anglers Handbook. Exception lakes in NE region season changed to align with trout season (Apr 1-Sep 30). All lakes with extended CP season also open to SMB in NE region. Covid19 pandemic delayed season opening and tournaments not permitted.
2021	Apr 1-Oct 31 (5, 25 Hants Co.) Extended season lakes: Apr 1-Dec 31 (3)	Closed all year. Some exceptions: Apr 1-Sep 30 (25)	Apr 1-Dec 31 (3) SS (SBMAs): May 1-Jun 15 (0)	Dobsons Lake (Guysborough Co.) closed to all angling for all species due to detection of SMB, the first confirmation in this watershed.
2025	Apr 1-Oct 31 (5, 25 Hants Co.) Extended season lakes: Apr 1-Dec 31 (3)	**Open season coincides with trout (Mandatory retention)**	Apr 1-Dec 31 (3) SS (SBMAs): May 1-Jun 15 (0)	Mandatory retention of SMB in the NE region and in all waters of the West Branch LaHave River. SMB angling reopening in NE region, open season coincides with trout season.

in 2013. These aimed to enhance legal ramifications for individuals found with live fish and dissuade illegal introductions.

In 2020, the boundary line between the two SMB management areas was adjusted slightly and described in detail in the Anglers Handbook for the first time (Hwy 102 from the junction of Hwy 104, 118, 107 and 328). In the NE region the season was changed to better align with the trout season (Apr 1-Sep 30), and all lakes with extended CP seasons were also open to SMB. In 2025, mandatory retention was enacted in the NE region with SMB angling permitted during trout season. A map showing the NE and SW AIS management regions was included in the 2025 Handbook for the first time (Fig 3, NSDFA 2025).

CP Regulation Changes

Regulation changes for CP angling since 2000 have been less complex as they have been managed as an invasive species consistently across both the NE and SW regions of the province. CP angling has always been permitted during any sportfish open season (salmon, trout, SMB). There was no set bag limit until 2002, when a province-wide limit of 25 was introduced. From 2002 until 2018 CP angling opportunities continued to expand and increase through the addition of extended seasons, 'open all year' CP lakes, and winter CP angling opportunities. In 2018, the provincial bag limit was increased dramatically to 100 fish per day. Finally, in 2025 mandatory retention of CP was enacted province-wide (NSDFA 2025).

Tournament Trends

The increased distribution of SMB in western Nova Scotia, combined with a growing popularity for this sportfish among anglers, led to the establishment of competitive SMB sport fishing tournaments in 1982. These provincially sanctioned tournaments were concentrated among central and western lakes where SMB had been introduced and popular fisheries for them already existed. By 2025, many of the lakes where tournaments were historically hosted continue to sport annual events by recognized, long-standing fishing organizations. The main target species for these events has consistently been SMB, however, some groups also target CP as many lakes that are popular for SMB tournament angling have both species.

SMB tournament fishing is permitted only in areas they are managed as a sportfish, west of the established Highway 102 boundary. Tournament organizers must apply for permits issued by the province

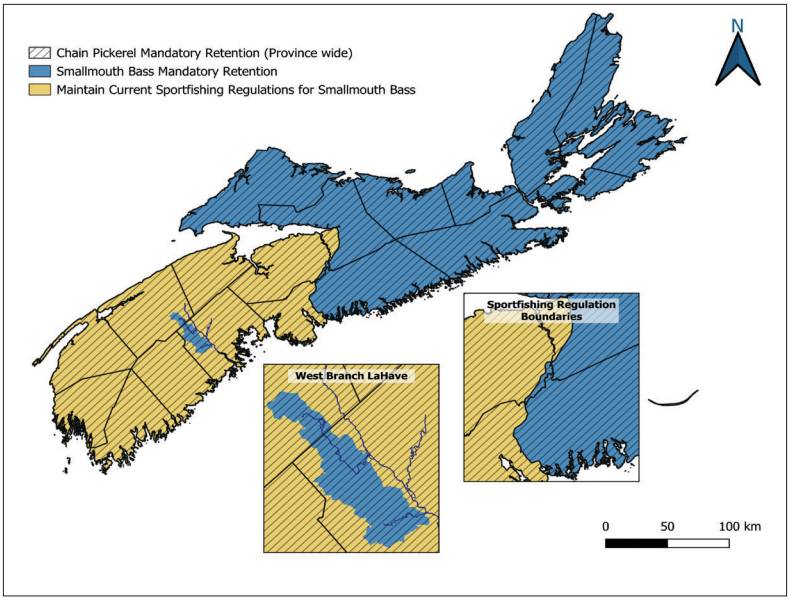


Fig 3 **AIS management boundaries established in Nova Scotia in 2025, illustrating mandatory retention zone for SMB (NE region and West Branch LaHave River) and CP (province-wide).**

to host sport fishing events and, subsequently, report summarized data from all events post-season as a condition of future permits – a policy that 1) allows the province to track tournament numbers and locations to maintain working datasets, and 2) keeps organizations accountable for data collection. In "Weigh-In" style tournaments, rules allow for a maximum of five fish to be captured and weighed at designated weigh-in stations before being released back into the lake. This tournament style has remained the most common amongst fishing organizations. "Catch-Photo-Release" (CPR) style tournaments do not weigh fish, opting instead for recorded lengths and photo evidence as proof of catch. The first CPR tournament was held in 2014 by an organization that continues to host multiple CPR tournaments annually present-day. This event style has grown in popularity in recent years, likely due to evolving trends in SMB fishing ethics (preference for immediate fish release versus holding in a livewell) and the increased access it affords anglers in remote/novel fishing sites (possible to use smaller watercrafts when a livewell is not required).

The majority of tournaments occur between early May to late September. Data reported to NSDFA between 2002 and 2025, shows a mean annual tournament number of 48.9 (± 5, SD), excluding 2020, which saw only four events due to COVID-19 pandemic restrictions. Outside of 2020, tournament numbers per year have ranged from 42 to 58 since 2002, illustrating a consistent popularity for SMB sport fishing over time. It should be noted that tournaments are limited by scheduling constraints as there are only so many weekends and accessible lakes of suitable size available for hosting events during the open season.

Despite changes in management strategies and increased public awareness of AIS, the consistency in annually recurring SMB tournaments indicates a continued interest in fishing for SMB among certain anglers. Over time, trends regarding tournament timing and target species have appeared in direct response to SBM regulation changes in the SW region. By 2013, there were growing concerns being voiced by tournament anglers regarding fishing SMB during their spawning season. These concerns contributed to NSDFA's decision to maintain spawning season restrictions within SBMA's (zero retention, May 1-Jun 15), while dropping it outside SBMA's. Our records indicate a voluntary decrease in the number of tournaments hosted within spawning season from 2013 onward. Mandatory retention of CP has recently resulted in many SMB organizations that have historically included CP as a secondary target species in their events to omit it entirely for the 2026 season. This is likely due to the logistical challenges of retaining all CP caught during day-long tournaments, as well as a preference and culture of catch and release fishing amongst some tournament anglers and organizations. Overall, it is evident through tournament data that Nova Scotia's popular SMB sport fishery has evolved and changed over time alongside NSDFA's management strategies for SMB.

Habitat Modification

In addition to regulatory efforts, active stream habitat restoration initiatives spearheaded by non-governmental organizations (NGOs) have made notable progress. The Nova Scotia Salmon Association's Adopt-A-Stream program provides funding and guidance to NGOs to focus on rehabilitating degraded habitats and enhancing connectivity across watersheds. Although these efforts can enhance connectivity for native species, they may also inadvertently facilitate the spread of invasive

species (Rahel 2007). Therefore, it is crucial to maintain physical barriers that inhibit the migration of AIS (Carpenter and Terrell 2005). Recent recognition of the role that connectivity enhancement plays in facilitating AIS spread has become a pivotal consideration in decision-making processes concerning barrier removals within the Adopt-A-Stream Program (CARP 2020). Provincial and federal agencies, NGOs, and community groups have recently begun collaborating to integrate AIS considerations more effectively into the regulatory frameworks for restoration and fish passage initiatives.

To combat the spread of AIS while protecting native habitats, various physical barriers have been constructed and trialed, including innovative designs like barrier falls intended to limit upstream migration (Novinger and Rahel 2003, Thompson and Rahel 1998). For example, in 2019, barriers were established in Kejimkujik National Park, Nova Scotia, to prevent the colonization of CP in upstream lakes (Parks Canada 2022). Although barriers at Kejimkujik did not achieve the intended exclusion, the project showcased a novel design approach and a rapid installation timeline that offered important lessons for future barrier development. Exclusion barriers are typically temporary, and their success is enhanced when the goal is to limit upstream movement rather than downstream movement (Rahel 2013). Additional measures implemented by NSDFA include earthen berms with water control structures and fish exclusion screens, and specially designed temporary barrier nets aimed at containing SMB populations in conjunction with mechanical removal efforts.

Chemical Control Methods

Chemical control methods, particularly the use of piscicides like rotenone and Antimycin A, have proven to be effective strategies for the eradication of invasive species (Halfyard 2010, Rytwinski *et al.* 2019). Rotenone has been employed in a limited number of management initiatives in the Maritimes over the past century. One of the first documented rotenone applications in Canada occurred in 1936 in Second River, a tributary of the River Philip, Nova Scotia, to reduce the wild salmonid population above the historic Cobequid Fish Hatchery in an effort to reduce risk of disease (McGonigle and Smith 1938). In New Brunswick, rotenone was used successfully in Despres Lake to eradicate CP (Connel *et al.* 2002) and unsuccessfully in the Miramichi River for SMB (Ward 2020). Rotenone had not been used in Nova

Scotia since 1952 (Hayes and Livingstone 1955), however, given the additional spread of AIS into un-impacted areas in recent years, a more aggressive approach to AIS management was adopted by NSDFA, including the use of rotenone to prevent the spread into the eastern region of the province (Fig 1).

Upon detection of SMB in Piper Lake, St, Mary's River in 2019 and subsequently in Dobsons Lake, Cole Harbour River in 2020, a rapid response was initiated involving containment, angling and eDNA surveys in surrounding systems, to evaluate the scope of the problem and target removals using nets and electrofishing. In Piper Lake, de-watering to induce winter kill was also attempted but was not effective in eradicating SMB. Both Piper and Dobsons lakes are headwater lakes, and the decision to pursue chemical eradication using rotenone was made to protect the freshwater ecology and native sport-fisheries in downstream waters and to prevent these lakes from becoming sources for future illegal introductions. Treatments were carried out in accordance with Finlayson *et al.* (2018) using Noxfish® Fish Toxicant II (5% rotenone) in Piper Lake in October 2020 and Dobsons Lake in September 2022.

Post-treatment surveys and subsequent annual electrofishing assessments confirmed the successful eradication of SMB in both lakes (NSDFA unpublished data). Repopulation of native fish communities within the treated lakes was achieved through natural migration following the removal of temporary containment barriers. Surveys suggest that the eradication efforts were effective in both lakes, and indicate fish, invertebrates, and zooplankton (McCallum Environmental Ltd. 2021, 2023, NSDFA unpublished data) can recolonize vacant habitats within one to two years in Nova Scotia. This finding is consistent with observations in the literature (Kiser *et al.* 1963, Peterson *et al.* 2011, Pham *et al.* 2017, Sandodden *et al.* 2022).

CONCLUSIONS

Invasive SMB and CP have broad-ranging impacts on native aquatic species in Nova Scotia, contributing to declining BT populations and increasing annual catch rates for AIS. In recent years, many anglers have underscored the critical importance of controlling AIS to enhance Nova Scotia's sport fishery (NSDFA 2012a). However, the notable expansion of SMB and CP populations is primarily attributed

to illegal introductions and subsequent natural migration through interconnected aquatic systems. The freshwater systems in Nova Scotia lack natural resistance to the establishment of invasive species such as SMB and CP, resulting in increased spread into new habitats and likely broader ecological impacts. To tackle the numerous challenges posed by these AIS, resource allocation by managers necessitated a shift from traditional departmental focus on native sportfish to robust policy implementation and collaborative initiatives targeting AIS. In recent years, a series of strategies aimed at combating illegal introductions while preserving native fish populations and restoring ecological balance have been implemented (Loppnow *et al.* 2013). These proactive strategies have included improved monitoring, enforcement of stricter regulations, containment measures, targeted eradication efforts, mandatory retention regulations, and increased public awareness efforts (Rahel 2004).

By addressing connectivity and employing various control mechanisms designed to limit the spread of invasive fish, these strategic initiatives could significantly contribute to the protection and preservation of native aquatic habitats. Continuous monitoring, assessment, and adaptation is critical to ensuring the long-term sustainability of native fisheries and maintaining ecological integrity within the province's freshwater ecosystems.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 551-577

LEAD, MERCURY AND OTHER METAL(LOIDS) IN BALD EAGLES (HALIAEETUS LEUCOCEPHALUS, KITPU), IN NOVA SCOTIA (MI'KMA'KI)

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ABSTRACT

Multiple tissues and feather types from seven adult male bald eagles (*Haliaeetus leucocephalus*, kitpu) were analysed for lead, mercury, arsenic, selenium, uranium and other elements via ICP-MS and direct mercury analyzer. Lead concentrations were consistently highest in bone tissue. Mercury concentrations were most elevated in organ tissues (heart, liver, kidney) but did not exceed published toxicity thresholds for large birds. Molar concentrations of selenium (Se) and mercury (Hg) for all tissues are

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correlated, and molar Hg:Se ratios were below published demethylation thresholds for waterbird mercury toxicity. Even so, it is recommended that eagle nestlings be monitored for mercury, given their higher vulnerability. Arsenic concentrations were detected in muscle, heart, kidney and liver tissues, but not in feathers, blood or bone. Uranium was measurable in all feather matrices, but not in any soft tissues or bone. Neither arsenic nor uranium were at concentrations of concern. Feather types exhibited consistent patterns, with the smaller nape feathers being below or close to detection limits for most elements. Primary, secondary and tertiary flight feathers from the seven sampled eagles were consistent in having more detectable element concentrations. To date, this dataset is among the very few to compare multiple tissues and feather types for a wide range of environmentally and biologically important elements for bald eagles.

Keywords: arsenic, blood, bone, feather, metals, mercury, muscle, organs

ACKNOWLEDGING KITPU'K IN MI'KMA'KI

It is a responsibility to work with kitpu'k (bald eagles), and we honour the messages carried in their feathers from across Mi'kma'ki, (spanning Nova Scotia, New Brunswick, Newfoundland, Quebec and Maine), the ancestral and unceded territory of the L'nu (the People). Through this work, we learn what is in the bones, tissues and blood of kitpu and understand their stories. The kitpu'k in this study were found in distress in Unama'kik, Pitukewa'kik, and Eskikewa'kik, and brought to the Cobequid Wildlife Rehabilitation Centre near Niktuipukewek, Sipekne'katik (Table 1). The lab work was carried out at Saint Mary's University in K'jipuktik, Sipekne'katik (Halifax). Given the importance of kiptu, bald eagles, in Mi'kma'ki (e.g., (Mack 2017), we included English, scientific and Mi'kmawi'simk (Hebda 2014) names for all species discussed here in that order where possible.

INTRODUCTION

Bald eagles (*Haliaeetus leucocephalus,* kitpu) across North America experience multiple environmental stressors (Burger and Gochfeld 2009; McTee *et al.* 2023; Nam *et al.* 2012; Scheuhammer *et al.* 2008a), with lead (Pb) poisoning often being among the most prominent of those concerns (Chételat *et al.* 2026; Slabe *et al.* 2022). Bald eagles and other birds across Canada exposed to spent Pb ammunition and fishing weights from scavenging carcasses left behind by hunters and anglers can accumulate significant concentrations of Pb and present

toxicological clinical signs of Pb toxicity, including those in Nova Scotia (Chételat *et al.* 2026; Fisher *et al.* 2006; Mathieu *et al.* 2020; Pain *et al.* 2009; Scheuhammer 2009). Currently, there are no provincial regulations for lead-containing fishing tackle and hunting shot, although there was a private member's bill introduced in 2023 (Bill 395, 2023). It is illegal to use lead shut, lead tackle or angling weights in federal parks and wildlife areas (CRC c. 1609, 2025; SC 1994 c.22, 1994).

In addition to Pb, there are other metal(loids) of concern to wildlife in the Atlantic region (Eleftheriou *et al.* 2017; Obeid, 2025). In particular, mercury (Hg) is of concern for freshwater ecosystems in eastern Canada (Environment and Climate Change Canada, 2017). Freshwater sportfish species and common loons loons (*Gavia immer,* gwimugw) in Nova Scotia have some of the highest tissue Hg concentrations across Canada and North America (Burgess *et al.* 2005; Depew *et al.* 2013), while piscivore fish species common in southern Nova Scotia has among the highest blood Hg concentrations for loons across North America (Burgess *et al.* 2005). This is associated with atmospheric deposition of Hg (primarily from coal burning for power generation), and the higher average acidity of Nova Scotia waterbodies, which supports increased bacterial methylation and bioavailability of Hg in ecosystems leading to vertebrates (Dennis *et al.* 2005; Depew *et al.* 2013; Little *et al.* 2015). Methyl-Hg (MeHg), the most toxic form of mercury, rapidly biomagnifies in food webs, meaning that higher-trophic animals feeding on fish and other aquatic organisms will accumulate elevated concentrations of Hg (Depew *et al.* 2013; Lavoie *et al.* 2013; Little *et al.* 2015). Elevated Hg accumulation in birds is associated with neurological and reproductive issues, flight issues, and development delays in chicks and juvenile birds (Scheuhammer *et al.* 2008a; Weech 2003).

Selenium (Se) is an essential trace element involved in many different functions of the human body (Combs 2001). Despite relatively high *total* Se concentrations in Nova Scotia soils (Jones *et al.* 2017), the naturally-acidic soils in the region generally have low *bioavailable* Se generally due to strong chemical bonds with Fe/Mn/Al oxides and other soil compounds limiting Se mobility (Dinh *et al.* 2019; Winter and Gupta 1979). Additionally, researchers have also found that Se-containing selenocysteine in tissues might be effective at counteracting Hg toxicity (Bowerman *et al.* 1994; Chapman *et al.* 2016; Eagles-Smith *et al.* 2009). This is often reported as molar ratios of Se:Hg with the assumption

that a molar excess of Se >1:1 confers protection from Hg toxicity (Eagles-Smith *et al.* 2009; Scheuhammer *et al.* 2008a).

Both arsenic (As) and uranium (U) are of geogenic origin in Nova Scotia and are found at elevated concentrations in well water. Arsenic is a class I carcinogen and human cancers (Carlin *et al.* 2016). Experimental studies have shown As contamination can also affect DNA methylation and increase oxidative stress biomarkers, both carcinogenic precursors, in passerines (Laine *et al.* 2021; Sánchez-Virosta *et al.* 2020). As occurs naturally in various geological units throughout Nova Scotia mainly as the mineral arsenopyrite (FeAsS) (Sangster and Smith 2007), and groundwater associated with those geological groups are often found to be elevated in As compared to national drinking water guidelines (Chappells *et al.* 2014). A review of As concentrations for Nova Scotia organisms have indicated that many species of invertebrates (up to 22 ppm As), freshwater fish (up to 3.5 ppm As), meadow voles (*Microtus pennsylvanicus*, up to 6.2 ppm As) and shrews (*Sorex cinereus*, up to 0.28 ppm As) can have elevated As (LeBlanc *et al.* 2019) – all of which are important prey items for bald eagles in eastern Canada (Cash *et al.* 1985; Stocek 2000).

Nova Scotia has extensive U deposits throughout the province (Drage and Kennedy 2013). While uranium mining is not presently allowed, untreated well water at some central Nova Scotia regions have been found to have elevated U (Drage and Kennedy 2013; Samolczyk *et al.* 2012), and clinical studies indicate that humans exposed to elevated U in Nova Scotia have corresponding elevated U in their hair (Moss *et al.* 1983; Zamora *et al.* 2002). There are no U concentration data for Nova Scotia birds, and globally, most studies focus on marine birds (Bond and Lavers 2011; Boryło *et al.* 2010; Strumińska-Parulska *et al.* 2013). Given the concern regarding U in Nova Scotia, we include this element in our overview.

Studies detailing contaminants in bald eagles and other raptor species for eastern Canada are quite limited especially for Nova Scotia (NS). Tissue studies to date in the Atlantic provinces have focused on legacy organic contaminants such as DDT and PCB (Dominguez *et al.* 2003; Obeid 2025; Woodley *et al.* 2004), rodenticides (Obeid 2025) as well as lead, mercury and selenium (Dominguez 1999; Obeid 2025; Scheuhammer *et al.* 2008b). Specifically for metal(loids), Chételat *et al.* (2026) analysed 60 liver samples from eight scavenging bird species in Nova Scotia as a part of a national survey of 1097 livers. They found

that bald eagle liver concentrations exceeded the Pb risk threshold of 20 ug/g dw liver the most often compared to other bird species (Chételat *et al.* 2026). Obeid (2025) as a part of a larger rodenticide survey, tested 6 livers from several raptor species for lead. They found 2 bald eagles with elevated lead (>30 ppm), one exhibiting toxicosis, although there was no note indicating where those 2 bald eagles were originally from. Scheuhammer *et al.* (2008b) reported elevated concentrations of Hg and Se in brain and liver tissue for bald eagles (N=89), mostly from British Columbia (BC) and NS. Dominguez *et al.* (1999) analysed blood samples from bald eagle nestlings and 2 adult eagles found dead (unspecified causes) from Newfoundland and found low concentrations for mercury, lead and other metal(loids). In Nova Scotia, data on lead bioaccumulation are mostly limited to intake reports at wildlife rehabilitation centres (Mathieu *et al.* 2020) and are not extensively documented in peer-reviewed literature for Nova Scotia.

The studies above typically focus on increasing number of fewer tissue samples (e.g. liver or blood) in order to assess geographical trends. Comparisons of multiple tissues and feather types for contaminant trends within the same bird is not common, but essential if modelling and risk exposure based on environmental concentrations can be conducted for bald eagles. Because bald eagles are protected species in many North American jurisdictions including Nova Scotia, many bald eagle and other Falconiformes contaminant datasets are necessarily limited to non-lethal or/and non-invasive sampling, e.g., blood, feather and egg analyses (Beyer and Meador 2011) and intake testing for rehabilitation of injured birds (Mathieu *et al.* 2020). Our objective was to establish a pilot project to survey lead, mercury and other elements in multiple tissues and feather types in NS. Ultimately, a database containing multi-tissue analysis and comparing trends of various elements across tissues and feathers within whole birds will eventually support better predictive modelling of whole-body contaminant burdens and toxicology estimates based on feather and blood monitoring datasets for Nova Scotia.

METHODS

Bald eagle sampling

The Cobequid Wildlife Rehabilitation Centre (CWRC, est. 2001) in Hilden, Nova Scotia (Niktuipukewek, Sipekne'katik) has become one of the main centres in the Maritimes for receiving and rehabilitating

injured and poisoned birds of prey. CWRC All intake raptors, loons and most waterfowl undergo capillary blood Pb testing using a LeadCare ® II Blood Lead Analyzer, a point-of-care electrochemical (anodic stripping voltammetry) diagnosis instrument, which includes adding treatment lysing reagent to the capillary tube containing a few drops of whole blood prior to analyses (Magellan Diagnostics 2021). Unfortunately, in some cases, birds arrive in a state that do not allow complete recovery due to serious injuries from accidents, electrocutions and severe Pb poisoning. In those cases, euthanasia under the oversight of a professional veterinarian is required, and the carcasses undergo necropsy.

Given the high costs of laboratory analyses and our plan to sample 11 types of tissue & feather samples for each bird, budgetary logistics strictly limited the total number of birds which we could sample. Therefore, to maintain consistency, we scanned and reviewed intake charts, including blood LeadCare© test results, x-rays (Fig 1) and necropsy notes, and WildONE logs for the available carcasses from 2017 and 2018 and stored in the CWRC freezer. Prior to selection of the eagle carcasses, we met with Mi'kmaq leaders (see acknowledgements) to discuss our approach, selection criteria and learn about the deep cultural significance of ki'tpuk in Mi'kmak'i.

Based on the guidance, we focused on adult male eagles which (Table 1) spanned a range of blood Pb including "high" Pb (>65 mg/dL, 2 birds); "moderate" blood Pb (10-30 mg/dL, 3 birds) and "low" Pb (<10 mg/dL, 2 birds), and all were males based on necropsy findings. The selected eagles were admitted to CWRC throughout the year including April (2 eagles), May (2), June (1), August (1) and November (1), but we did not see discernable trends in blood Pb with month in this sample set. The eagle carcasses processed for this study were covered under a Nova Scotia Natural Resources Scientific Permit to L.M. Campbell, signed June 6, 2018, with review and oversight by the Saint Mary's University Animal Care Committee. This project was funded by a Nova Scotia Habitat Conservation Fund grant NSHCF18_14.

Sample processing & laboratory analyses

All eagles were measured and dissected at Saint Mary's University, Halifax, Nova Scotia. Pectoral muscle, heart, liver, kidney, coagulated blood and rib-cage bones were sampled and dried at low temperatures (<60°C). Feathers, including nape, chest, and 3 types of wing feathers (primary, secondary and tertiary), were carefully removed, cleaned

Table 1 **Bald eagle intake notes and morphometrics. The Intake date (M/D/Y) and number of days in the clinic prior to death are listed. All eagles were euthanized except for BE 2018-038, which died shortly after intake. Blood Pb was measured upon intake (2 "high", >65; 4 "moderate", 10-30; and 2 "low", <10 ug/dL). All eagles were necropsied at CWRC, and confirmed as mature adult males. All bird intake data are also in WildONE (Wildlife Centre of Virginia).**

CWRC Bird ID	Intake date (N days)	Intake Blood Pb (ug/dL)	Rescue county, Mi'kma'ki location	Rescue circum-stance	Injury	X-ray	Wgt (kg)	Body length (cm)	Wing chord (cm)	Humerus length (cm)	Tarsus length (cm)	Culmen length (cm)	Bill depth (cm)	Hallux length (mm)
BE 2017-089	05/17/2017 (1)	6	Cape Breton Unama'ki	Failure to thrive / Mal-adaption	Musculoskel/ Joints/ Liga-ment Tissue /Forelimb / wing/shoulder girdle	Y	~	73	59.8	28.4	68	50	31.9	21.5
BE 2017-120	05/31/2017 (0)	6.9	Pictou Piktuk	Collision / Stationary object / Walls / windows	Nervous System/ CNS-central/brain	Y	~	74.5	65	26	94.9	54.7	36.5	20.9
BE 2018-33	04/06/2018 (1)	10	Colchester Sipekne'katik	Failure to thrive / Maladaption	Nervous System/ CNS-central/brain	Y	~	72	58	26	60	48.6	30.4	21
BE 2018-120	06/13/2018 (0)	10.7	Colchester Sipekne'katik	Behavioral Stranding	Musculoskel/ Skeleton/ Non-fracture/ Hindlimb/ pelvis	N	2.415	74.8	60	26	59.3	50.5	30.2	20

Table 1 cont'd.

CWRC Bird ID	Intake date (N days)	Intake Blood Pb (ug/dL)	Rescue county, Mi'kma'ki location	Rescue circumstance	Injury	X-ray	Wgt (kg)	Body length (cm)	Wing chord (cm)	Humerus length (cm)	Tarsus length (cm)	Culmen length (cm)	Bill depth (cm)	Hallux length (mm)
BE 2017-324	08/28/2017 (17)	22	Guysborough Eskikewa'kik	Failure to thrive / Maladaption	Nervous System/ CNS-central/brain	Y	~	70.9	55.4	25.1	62.2	57.7	35.5	24
BE 2017-391	11/24/2017 (1)	>65 (High)	Cape Breton Unama'ki	Failure to thrive / Maladaption	Nervous System/ CNS-central/brain	N	3.4	83	64.5	30	85.5	54.6	34.1	30.1
BE 2018-038	04/18/2018 (0)	>65 (High)	Colchester Sipekne'katik	Behavioral Stranding	Nervous System/ CNS-central/brain	N	3.75	77.2	64.5	26.9	93.7	57.8	36.4	23.1

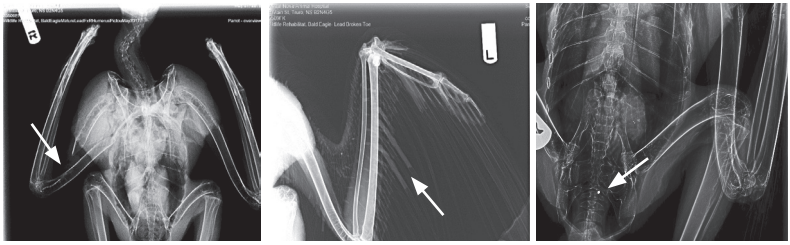


Fig 1 **Representative X-ray images of three eagles upon intake at the Cobequid Wildlife Rehabilitation Centre, Nova Scotia. The left is for BE2017-120 and shows a broken left humerus (indicated by arrow). The middle is of BE2017-324's right wing with clear images of feather camasuses. The right image is of an immature eagle (not included in this study), with bright spots in the digestive tract indicating lead particles, likely from feeding on an abandoned carcass left behind by hunters. The presence of visible Pb particles (indicated by arrow) in x-rays is unusual because visible Pb particles are not often seen in eagles upon intake. Eagles typically ingest mostly fragmented Pb from ungulate carcasses and gut piles left behind by hunters. Many of the fragments ingested from carcass remains are minuscule, and it does not take long for an eagle's powerful gizzard to grind those fragments down and entirely absorb the lead into the blood stream.**

with acetone & water, air-dried (Keute *et al.* 2024), and the barbs removed from the rachis using acetone-cleaned scissors. Tissues and cleaned feathers were pulverized into smaller sizes using acetone-cleaned mortar & pestles, homogenized to fine powder with a Retsch MM400 mixer mill and put in acid-cleaned vials. Prepared samples were shipped to the Analytical Services Unit, Queen's University, accredited by Canadian Association for Laboratory Accreditation to the standards of ISO/IEC 17025. Hg was measured on a Milestone Direct Mercury Analyzer. A total of 30 elements (Ag, Al, As, Ba, Be, Bo, Ca, Cd, Cr, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sn, Sr, Ti, Tl, U, V and Zn) measured via ICP-MS. Calcium (Ca) concentrations of bone material exceeded the ICP-MS maximum detection limits so were measured by ICP-OES. Quality controls included blanks, prepared standards, duplicates and the NRC certified reference material TORT-2. After processing, all eagle carcasses were returned to CWRC as per Nova Scotia Department of Natural Resources protocols.

Data analyses

The primary focus of this study is on tissue concentrations & distribution of Pb, Hg and Se in bald eagles, but we also examined As and U, both of which are geogenic elements of significant environmental concern in Nova Scotia (Figs 2-6). It should be noted the sample set

is not randomized due to the nature of sampling, and therefore this set of eagles may not be representative of the bald eagle populations in Nova Scotia. Additionally, we have chose to retain the different units for ICP-MS (mass-based, µg/g) and point-of-care measurements (volume-based µg/dL for LeadCare© results) to ensure consistency with both literature and veterinary intake report conventions. We have published our full dataset of all measured elements in our Dataverse account (Campbell, 2026a), which may be of use for future wildlife and ornithology investigations.

Depending on tissue type, a number of elemental values were below the Method Detection Limit (MDL). All tissues had Hg and Fe consistently detected above MDL. Blood samples had the most results below MDL, with only 5 elements (including Mg, K, and Na) measured consistently above MDL. Bone samples had 18 elements (including) consistently above MDL. Pectoral muscle had 14 elements (including) above MDL. If more than 4 samples for each tissue type were below MDL, then we removed that tissue type from statistical analyses. An exception was blood Pb (5 blood samples below MDL) given the importance of lead contamination to birds in North America. If there were less than 3 samples per tissue type below MDL, then we adjusted for left-censoring by using the half of the LOQ value (Campbell 2026a). Eight elements (Si, Be, Bo, P, Ag, S, Tl, and Sn) were subsequently removed from the data analyses due to having no values above LOQ or having insufficient number of values above MDL for all tissue and feather types.

Lead (Pb), mercury (Hg), selenium (Se), arsenic (As) and uranium (U) separated by tissue and feather type. Box and whisker plots (Figs 2-6) were prepared based on average, standard deviation, minimum and maximum value summary statistics. The full dataset (Campbell 2026a) and the table of summary statistics (Campbell 2026b) are published in our Dataverse account.

RESULTS & DISCUSSION

Lead

Bone Pb concentrations (20±15.5 µg/g, 5.7-44.0 µg/g, Fig 2A) was most elevated, followed by liver Pb (11.7±20.1, 0.5-44.0 µg/g) and kidney Pb (5.3±7.7, 0.4-19.0 µg/g) concentrations (Fig 2). Pb concentrations from ICP-MS and point-of-care LeadCare ® II Blood Lead Analyzer

(Magellan Diagnostics, 2021) were correlated (Fig 3). Franson and Pain (2011) reviewed lead poisoning in birds across the world and define "threshold concentration" as the tissue concentration at which measurable clinical (e.g., overt symptoms) and subclinical (e.g., less visible) effects can occur. The lead tissue thresholds for each documented tissue type (blood & bone, 20 µg/g; liver, 6 µg/g; kidney, 4 µg/g) are indicated in Fig 2a (Franson and Pain, 2011). Accordingly, Pb concentrations in bone (3 eagles), kidney (2 eagles) and liver (2 eagles) tissues were above avian threshold for subclinical Pb poisoning (Franson and Pain, 2011). The 2 eagles with consistently elevated tissue Pb concentrations above the listed tissue thresholds (BE2017-391, BE2018-038) all also were in the "high Pb" category, based on intake point-of-care blood lead values (>65 µg /dL), while the third eagle (BE2017-324,) with elevated bone (but not kidney or liver) Pb concentrations was the next highest (point-of-care, 22 µg/dL). All three exhibited extreme distress upon intake, although BE2017-324 had the longest intake period (17 days) before euthanasia. Lead concentrations in feathers ranged between 0.36 to 9.4 µg/g (Fig 2B).

Recent surveys of birds of prey across Canada (liver only) and the USA (bone, liver, feather) indicated that there is a high proportion of eagles suffering from both chronic and acute lead poisoning (Chételat *et al.* 2026; Slabe *et al.* 2022). Our results above are within the reported

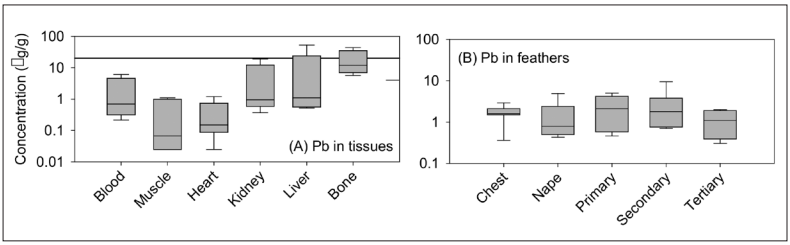


Fig 2 **Box plots showing maximum, minimum, 25th & 75th quartiles, median (solid line) & mean (dashed line) values for Pb concentrations in each type of tissue (Fig 2A) and feather (Fig 2B) for eagles processed in this study (n=7). The horizontal lines in Fig 2A indicates potential tissue thresholds postulated for bald eagle Pb poisoning symptoms from a literature review (Franson and Pain 2011). The solid line indicates the postulated blood & bone threshold for subclinical concentrations (20 mg/g) dotted line indicating upper threshold limit for subclinical concentrations in liver (6 mg/g), and the dashed line indicating upper threshold for subclinical concentrations in kidney tissues (4 mg/g). The upper limit of 100 indicates consistently severe clinical symptoms for most bird species if measured in blood. A table of summary statistics can be found at: doi.org/10.5683/SP4/C6C7BT.**

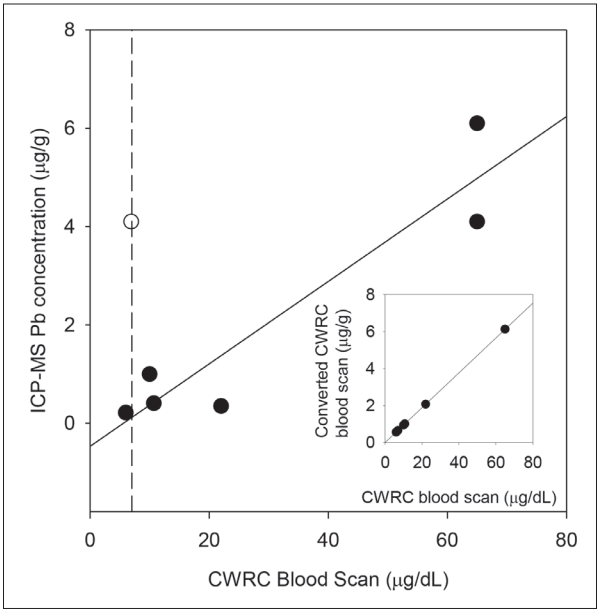


Fig 3 **Comparison of point-of-care blood scans at the Cobequid Wildlife Rehabilitation Centre (CWRC) and ICP-MS analyses of blood lead (Pb) concentrations for 7 adult bald eagles (y=-0.19+0.07(x), r^2=0.87, p=0.7). The empty circle is an outlier which was removed from the regression. The inset graph shows the relationship between converted CWRC point-of-care data using human blood density of 1.060 kg/L (Cutnell and Johnson 1998), which indicates that mg/dL and mg/g are near-analogous units for blood concentrations. The dashed line indicates the lowest published clinical Pb concentration (7 mg/dL) upon which bald eagles have demonstrated clinical symptoms. A table of summary statistics can be found at: doi.org/10.5683/SP4/C6C7BT.**

ranges for USA bald eagle femur bone (12±21 µg/g), liver (19±40 µg/g), peak feather (unspecified type of feather, 1.9±1.3 µg/g) and blood (83±271 µg/dL) from the Atlantic flyways (Slabe *et al.* 2022). In British Columbia, 37% of 294 sick, injured or dead bald eagles exhibited signs of significant Pb exposure, with 23% were sub-clinically exposed, while 14% were poisoned (Elliott *et al.* 1996). A survey of over 700 bald eagles and golden eagles (*Aquila chrysaetos*) from rehabilitation clinics across western Canada (BC, Alberta, Saskatchewan, Manitoba) found Pb concentrations (>0.2 ug/mL blood) for a significant number of birds, with high blood Pb concentrations geographically associated with areas of highest hunting density (Wayland *et al.* 2003; Wayland and Bollinger 1999). Additionally, environmental Pb exposures in bald eagles is of particular concern for hatchlings and juveniles due

to smaller sizes and development stages most vulnerable to poisoning (Hanley *et al.* 2022).

Reviewing the CWRC clinical intake logs (Table 1), we did not find correlations between immediate clinical symptoms upon intake and point-of-care blood Pb concentrations. Clinically diagnosing Pb poisoning in live bald eagles is challenging because birds can present highly variable behaviour and physiological responses among individuals. Intake logs indicate that common clinical signs of Pb toxicological responses include anisocoria (eye pupil size difference), profound weakness with a dropped head and slumped wings, laryngeal paralysis with a whistling noise, and tail feathers being stained with bright green watery feces. Tremors and seizures generally carry a grave prognosis. Based on CWRC log sheets, eagles with moderately-elevated blood Pb levels during nesting season may appear to be clinically normal, while other birds admitted to CWRC following hunting season with point-of-care blood Pb levels as low as 7 ug/dL were clinically affected. Published blood lead kinetics and the duration of Pb accumulation in birds of prey follow a consistent trend (Krone 2018), with blood Pb becoming elevated after 24 hours of ingesting fragments of spent Pb ammunition. Most blood Pb is bound to proteins and sulfhydryl compounds with a very small proportion found in serum. The half-time of blood Pb can be on the order of weeks to months since ingestion, leading to accumulation in bone, liver and kidney tissues (Franson and Pain 2011). Pb turnover in kidney and liver is about 1-3 months whereas Pb in bone is essentially immobilized with the exception of bone remodelling and eggshell production in female birds (Gangoso *et al.* 2009; Scheuhammer 1987). At the time of this study, Pb ammunition and weights are still widely available for sale for general hunting and angling in Nova Scotia, and alternative ammunition can be difficult to find. Even so, there has been public campaigns across eastern Canada to encourage hunters and anglers to switch to other non-Pb ammunition and weights such as those made with copper and bismuth (Chui, 2016).

Mercury & selenium

Hg in bald eagle tissues (Fig 4A) tended to be most elevated in kidney (9.7±8.3, 2.7-25.1 µg/g) and liver (4.1±2.5, 1.0-8.6 µg/g). The next group of Hg concentrations include muscle (1.4±0.7, 0.03-1.1 µg/g), blood (2.7±1.2, 0.9-6.1 µg/g) and heart tissue (1.5±0.6, 0.6-2.1 µg/g).

Bone (0.26±0.1, 0.2-0.4 µg/g) tissue had the lowest concentrations. Most tissues had Hg concentrations below postulated death thresholds for kidney (40 µg/g) and liver (20 µg/g) (Shore *et al.* 2011), but liver Hg was just above the postulated reproductive toxicity threshold of 2 µg/g (Shore *et al.* 2011). Feather Hg concentrations (Fig 4B) were consistent among all feather types, and all were below the feather Hg toxicity threshold (Evers *et al.* 2005). Selenium was most elevated in kidney (5.1±1.8, 3.3-8.2 µg/g) and liver (2.7±1.1, 1.7-4.9 µg/g) tissue, relative to other tissues, and was not detected in blood (Fig 4C). Feather Se concentrations ranged widely in secondary feathers (Fig 4D) but were not detected in chest or nape feathers.

The antagonistic role of selenium in demethylation (and detoxification) of Hg in wildlife, including birds, is well documented, although the actual mechanisms are still being delineated (Manceau *et al.* 2021). Molar concentrations of Se and Hg for all tissues are correlated (Fig 5). Furthermore, the sampled eagles had molar Hg:Se ratios below the demethylation threshold for Hg toxicity (8.5 µg/g) in waterbirds (Eagles-

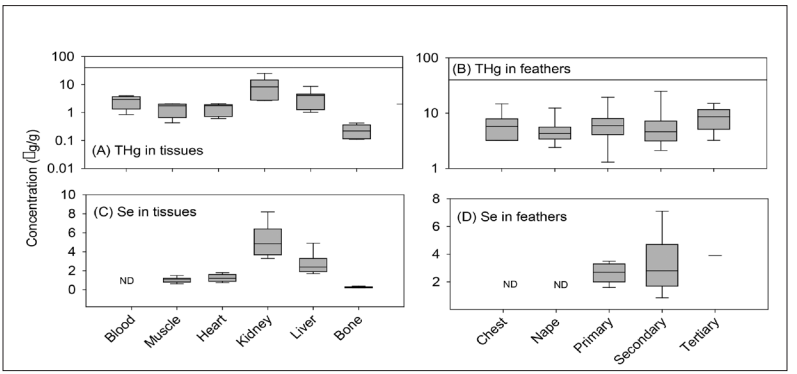


Fig 4 **Box plots showing maximum, minimum, 25th & 75th quartiles, median (solid line) & mean (dashed line) values for mercury (Hg) and selenium (Se) concentrations in each type of tissue (Fig 4A, C) and feather (Fig 4B, D) for 7 eagles processed in this study. "ND" indicates that particular element was not detected for that tissue/feather type. The horizontal lines in Fig 4 A indicates potential tissue thresholds postulated for bald eagle Hg poisoning symptoms from a literature review (Shore *et al.* 2011). The solid line indicates a postulated upper kidney Hg concentration threshold of 40 mg/g associated with death, the dotted lines indicate liver Hg concentration threshold of 20 mg/g associated with death, and the dashed line indicate the liver Hg concentration threshold for reproductive impact of 2 mg/g. The solid line in Fig 4B indicates the suggested upper Hg threshold limit of 40 mg/g for loon feathers in north-eastern North America regions (Evers *et al.* 2005). A table of summary statistics can be found at: doi.org/10.5683/SP4/C6C7BT.**

Smith *et al.* 2009), indicating that Hg concentrations may be a lesser concern for those male bald eagles. The relatively low Hg exposure and accumulation in the sampled eagles may be the result of a diverse diet incorporating marine and terrestrial prey with lower Hg concentrations than freshwater fish (Frenzel and Anthony 1989; Kozie and Anderson 1991; Stocek 2000).

Even so, nationally, Hg trends in bald eagles tend to be the most elevated in the Maritimes region (Scheuhammer *et al.* 2008a), which mirrors the trend for Hg in fish and common loons across Canada (Burgess *et al.* 2005; Depew *et al.* 2013). Bald eagles in Atlantic Canada consume a significant amount of fish, with over 60% of typical bald eagle diets in Nova Scotia and New Brunswick comprising of fish (Cash *et al.* 1985; Stocek 2000) and those in Newfoundland comprising of fish or birds (Dominguez *et al.* 2003). The increased Hg exposure through high-fish diets may still be presenting a risk to juvenile and hatchling bald eagles (Rutkiewicz *et al.* 2011; Scheuhammer *et al.* 2008a) which are more vulnerable to the risks of Hg toxicity (Scheuhammer *et al.* 2008a; Weech 2003). It is recommended that bald eagle nests in different areas of Nova Scotia be monitored via remote cameras to collect more information on prey type, feeding frequency and chick dietary composition (Houssein *et al.* 2021), and that nestlings be surveyed for blood and feather Hg trends across the region (Pittman *et al.* 2011).

Arsenic

Muscle (1.0±0.4, 0.7-1.4 µg/g), heart (0.9±0.6, 0.5-1.7 µg/g), kidney (0.9±0.3, 0.6-1.1 µg/g) and liver (1.3±0.7, 0.6-2.0 µg/g) tissues all had measurable As concentrations, while none of the feathers, blood or bone analysed in this study had measurable As concentrations above instrumentational or MDL limits. There is no published research on As accumulation in Nova Scotia bald eagles to date, although there have been published baseline studies for eagles in Alaska (feathers only), Iowa (excrement only) and a single adult eagle in Kansas (blood only) (Allen 1992; Burger and Gochfeld 2009; Reiter-Marolf *et al.* 2017).

British birds of prey species, kestrels (*Falco tinnunculus*) and sparrowhawks (*Accipiter nisus*, pi'jkwej) from a region of elevated As in southwest England had higher As in muscle (0.030-3.9 µg/g dw; 0.03-0.21µg/g dw, kestrels and sparrowhawks respectively), kidney (0.05-1.1 µg/g; 0.05-0.5 µg/g), and liver (0.04-1.4 µg/g; 0.04-0.50 µg/g) tissues

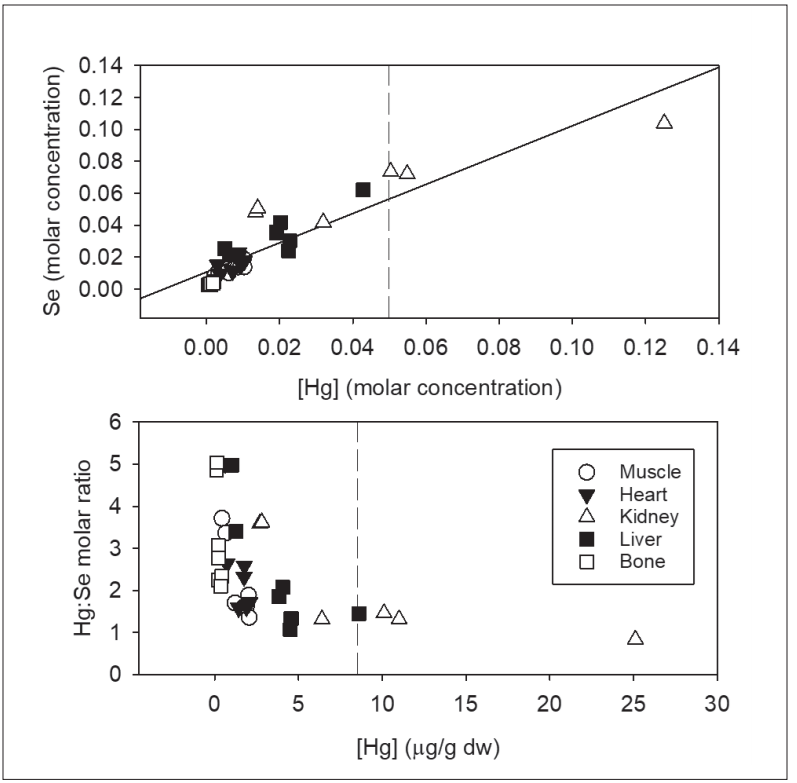


Fig 5 **Relationship between molar concentrations of mercury (Hg) and selenium (Se) in various tissues for 7 eagles processed in this study. Molar ratios of Se and Hg are significantly related ($y=-6.65+0.89$ (x), $r^2=0.82$, $p<0.05$). Feather trends did not exhibit a significant relationship between Hg & Se. The vertical dashed line is the modelled liver [Hg] demethylation threshold (8.5 mg/g dry weight liver) from a published study for waterbirds (Eagles-Smith *et al.* 2009).**

than those for same species from a reference site in south-west Scotland (Erry *et al.* 1999). A similar bird of prey investigation into osprey (*Pandion haliaetus*, ni'kmawe'su) nestlings from mining-contaminated and unimpacted regions of a large Montana (USA) river system indicated elevated blood As in nestlings from the more contaminated regions of the river system relative to those from unimpacted regions (Langner *et al.* 2012). Our data and the global literature suggest that bald eagles from Nova Scotia may be exposed to elevated arsenic and may be bioaccumulating high concentrations as a result and that further investigations are warranted.

Uranium

Our results indicate that bald eagles are accumulating total U in all feather matrices but there was no detectable U in any of the tissues sampled (Fig 6B). This is in line with human clinical literature which recommends hair samples for U monitoring (Zamora *et al.* 2002). The Nova Scotia bald eagle feather U concentrations ranged between <0.005 µg/g to 0.150 µg/g (Fig 6B), which places those birds at the lower end of the avian literature range. A survey of 234U, 238U and total U in 5 taxonomic groups of marine birds in Baltic Sea reported that fish-eating birds had the lowest U concentrations relative to those for herbivorous birds (Boryło *et al.* 2010). The authors also found that total U was consistently highest in feather matrices or in viscera for all birds, with average feather concentrations ranging from 6.3 µg/g in Eurasian coot feathers to 24 µg/g U in Great cormorant feathers. A similar study for flesh-footed shearwater feathers from the southern Pacific had a range of total U from 0.017 µg/g to 0.042 µg/g depending on their breeding region (Bond and Lavers 2011). Feeding ecology and dietary preference in eagles, in addition to the background concentrations of U may still be important factors. While accumulated U is likely not a concern for bald eagles in Nova Scotia, our results indicate that wing feathers may be a useful monitoring matrix for this element and those values are consistent with other avian studies.

Non-lethal sampling using feathers

Bald eagles will moult wing feathers consistently throughout the year (Mccollough 1989), so each feather provides a "snapshot" of contaminant exposure during the growth phase. This potentially provides a useful temporal overview of contaminant exposure during the different seasons. Documented moult patterns for bald eagles indicate that feather moult takes place from April to October, with peak moult in June & July for both wing and body feathers. Feathers are useful for assessing ages of young bald eagles up to three or four years old (Buehler 2020, McCollough 1989).

Furthermore, feather sampling is non-lethal and minimally invasive which can be done on live birds or after moulting. Non-lethal sampling approaches are especially important consideration when studying protected or vulnerable bird species (Peterson *et al.* 2019), and as such, feathers are among the most commonly sampled tissue matrix for bird contaminant studies (Gómez-Ramírez *et al.* 2014). In this limited

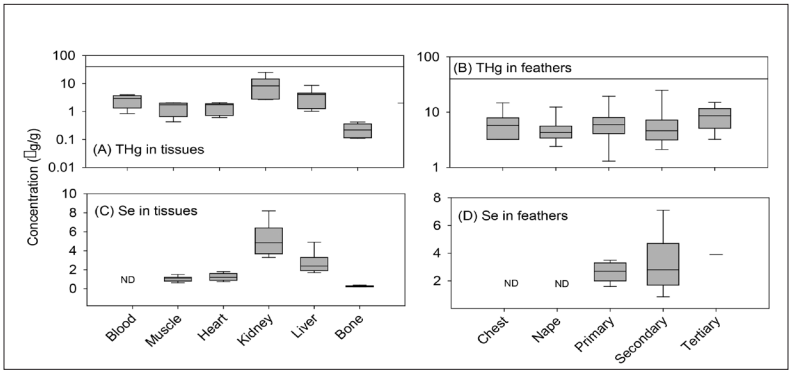


Fig 6 **Arsenic (As) concentrations in tissues and uranium (U) concentrations in feathers from eagles processed for this study (n=7). "ND" indicates that particular element was not detected for that tissue/feather type. Note that As was not detectable in any feather samples, while U was not detectable in any tissue samples. Both are naturally occurring geogenic elements of significant concern in Nova Scotia, and as a result, bald eagle tissues and feathers may represent a potential biomonitoring tool for both elements. A table of summary statistics can be found at: doi.org/10.5683/SP4/C6C7BT.**

study with 7 eagles, we did not find any correlations between feather and body tissue element concentrations for any element. This may be due to the mismatch between the timing of feather growth and the accumulation of contaminants during exposure, as well as the small number of eagles in our study significantly decreasing the power of the data analyses. Even so, feathers have been found to be a useful tool for spatiotemporal analyses (Pittman *et al.* 2011), to investigate long-term trends from historical collections (Rocque and Winker 2005) and as a "proxy" tissue for food web trophodynamics of bioaccumulating contaminants such as Hg (Einoder *et al.* 2018).

There are consistent variations in elemental concentrations across types of feathers, with the smaller nape feathers being consistently below detection limits. Chest feathers are most often used in studies as a minimally-invasive tissue matrix which does not harm the bird's ability to fly, and produces most consistent results for Hg and Pb (Burger and Gochfeld 2009; Peterson *et al.* 2019). However, in our study, several elements (Se, Co, V) were not detected in chest feathers but were detected in other feather types, including primary, secondary and tertiary wing feathers which had more numbers of detectable elemental concentrations. For a multi-elemental study, it would be recommended that the tips (~1 cm) of flight feathers be sampled to increase the range

of detected elements for analyses rather than using chest or nape feathers. In regards to live sampling of bald eagles (nestling to adults), moulting should be carefully considered when developing the feather sampling plan (Lodenius and Solonen 2013).

MANAGEMENT IMPLICATIONS

This study focused on key elements (Pb, Hg, As, Se, U) which are environmentally important in Nova Scotia. Lead trends for the seven adult eagles in this study are still of significant concern, underscoring the urgency of reducing the use of lead ammunition and weights in hunting and angling. Mercury concentrations, while of high environmental concern in Nova Scotia, appear to be below avian ecotoxicity thresholds for the sampled bald eagles based both on concentrations and molar ratios of Hg: Se. However, the Hg concentrations observed in adult eagles in this study would still be potentially concerning for hatchlings and juvenile eagles, and additional investigations would be warranted. Tissue As concentrations and feather U concentrations reveal that that bald eagles are accumulating geogenic elements of significant concern in Nova Scotia.

Acknowledgements Wela'lioq, K. Paul, B. Sylliboy and R. Sewell, for discussing Wela'lioq, K. Paul, B. Sylliboy and R. Sewell, for discussing the research project and the cultural importance of bald eagles in Mi'kma'ki with the team before we sampled the eagles. The CWRC staff, especially B. Boates, supported logistics and hosting our team who came with a portable scanner in the clinic to copy paper intake logs. D. Carruthers-Lay (Clean Foundation Summer Intern) worked with the team on dissection and processing of the bald eagles. The Atlantic Poultry Research Institute (Bible Hill, Nova Scotia / Weli-klu'lek, Mi'kma'ki) provided us with several whole chickens for dissection training. The authors do not have a conflict of interest with this project.

IN MEMORIAM

Dr. Helene Van Doninck was a well-respected and well-known wildlife veterinarian whose work had an impact across the Maritimes region in eastern Canada. Dr. Van Doninck was a teacher, mentor, leader and innovator whose work was cut too short due to ovarian cancer.

Dr. Van Doninck has been involved with oiled wildlife preparedness and response efforts and training programs across Canada and USA since 1995. In 2001, Dr. Van Doninck co-founded the Cobequid Wildlife Rehabilitation Centre, with a bald eagle recovery centre, which has led to hundreds of eagles, other bird species and wildlife successfully returning to their habitats. Dr. Van Doninck also advocated across Canada and the United States for reduction of lead bullets and fishing weights to protect wildlife. Dr. Helene Van Doninck is missed by many, and her legacy still lives on via her very successful advocacy and leadership on behalf of all wildlife.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 579-606

POPULATION GENETIC STRUCTURE OF AMERICAN BLACK BEARS (*URSUS AMERICANUS*) IN NOVA SCOTIA, CANADA

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ABSTRACT

The population genetic structure of American Black Bears (*Ursus americanus*) in the Maritimes Provinces, Canada, with an emphasis on Nova Scotia, was examined. The study used hunter-sourced tooth samples from across Nova Scotia, as well as samples from New Brunswick. Allelic variation was examined for a suite of 15 microsatellite markers. Population structure was assessed using a Bayesian clustering method (STRUCTURE) and by conducting an isolation by distance (IBD) test. Three weakly differentiated genetic subpopulations were found with their general geographic locations being New Brunswick, Northeastern Nova Scotia, and Southwestern Nova Scotia. The New Brunswick subpopulation had higher measures of genetic diversity as well as effective population size relative to both subpopulations in Nova Scotia, but in particular compared to the Southwestern Nova Scotia subpopulation. The Shubenacadie Canal system, primarily comprised of the Shubenacadie River and Shubenacadie Grand Lake, is the geological feature separating the two subpopulations of Black Bears found in Nova Scotia.

Keywords: Black Bears, gene flow, microsatellites, genetic diversity, inbreeding

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INTRODUCTION

Approximately one quarter of all assessed mammalian species are listed by the International Union for the Conservation of Nature as Vulnerable, Endangered or Critically Endangered (IUCN 2025). The principal threat to these species is anthropogenic impacts to landscapes (Baillie *et al.* 2004). These include habitat loss and habitat fragmentation, which often act synergistically (Segan *et al.* 2016). Because of these anthropogenic factors, populations of impacted species may lose allelic diversity, exhibit decreased levels of genetic heterozygosity and experience reduced gene flow and more inbreeding (Turnock *et al.* 2024). This reduction in genetic diversity and associated deleterious effects on population genetic structure has been called "genomic erosion" (e.g., Pinto *et al.* 2024). Large terrestrial carnivores are at particular risk of anthropogenic land impacts due to their extensive area requirements (Shafer *et al.* 2015). American black bears (*Ursus americanus*) are no exception to this trend, having lost nearly half of their range in the last century, largely due to habitat loss and fragmentation, and, to a lesser extent, over-exploitation (Pelton *et al.* 1999). Black bear populations in the more northern portions of their range exist in relatively undisturbed continuous habitats (Pelletier *et al.* 2012, Sawaya *et al.* 2014), whereas populations in the southern part of their range exist in highly fragmented landscapes (Dixon *et al.* 2007, Draper *et al.* 2017).

No large-scale studies have investigated the relative threats to black bears associated with anthropogenic impacts on habitats in Nova Scotia, Canada. Although the province is estimated to have ~75% forest coverage at present, a history of intensive forestry practices has led to heavily altered forest compositions and much of the province is managed for timber (Nova Scotia Department of Natural Resources Renewable Resources Branch 2017). According to Statistics Canada, Nova Scotia has experienced roughly a doubling of its human population in the last century. In addition to these anthropogenic factors acting within the province, the nearly insular nature of Nova Scotia may naturally hamper black bear movement and gene flow over a larger geographic scale. The narrow land bridge, the Isthmus of Chignecto, connecting the province to the rest of North America has been identified as a partial barrier to some mammalian species (e.g. moose, *Alces alces americana*, Scott *et al.* 2023, Scott and Hebda 2004, Beazley

et al. 2006), but not to others (e.g. coyotes, *Canis latrans* var, Power *et al.* 2015). Anthropogenic impacts including construction of highways, railways, wind turbines, communication towers, and agriculture and forestry activity have likely further reduced the ability of various mammals to move through this region (Nussey and Noseworthy 2018, Needham *et al.* 2020). It is not known how this geographic feature affects black bear movement.

Given the threats faced by many species, monitoring local populations to evaluate their viability using population genetic markers is important for wildlife management (Allendorf 2017). Particularly useful is the assessment of population genetic structure of a species in areas of interest (e.g. Pelletier *et al.* 2017, Wang *et al.* 2017). Such assessments involve using information gathered on the regional genetic composition of a species to distinguish patterns of genetic similarity and dissimilarity on a geographical scale. These assessments, consequently, allow the delineation of genetic subpopulation groupings, and with it the ability to identify gene flow patterns, and to estimate measures of genetic diversity. Accordingly, the objective of this study is to conduct a spatial population genetic analysis of black bears in Nova Scotia using tissue samples derived largely from hunter- and trapper-sourced black bears from across the province. Samples from New Brunswick were also obtained for comparative purposes. Ultimately, information gathered from this study will be useful to wildlife agencies to aid in making management decisions, with consideration for this species' regional conservation needs.

METHODS

Sample Collection and Processing

Black bear samples from Nova Scotia were supplied by the Nova Scotia Department of Natural Resources (formerly known as either the Department of Natural Resources and Renewables or the Nova Scotia Department of Lands and Forestry) from material obtained from hunters and trappers in 2017. Samples from New Brunswick, which originated from legally harvested, road killed, or euthanized nuisance black bears from 2017 and 2018, were supplied by the New Brunswick Department of Energy and Resource Development. Nova Scotia (NS) County of origin or New Brunswick (NB) Wildlife Management Zone (NB) included in the metadata for each sample. All samples provided

by these government agencies consisted of teeth. Because samples had already been collected by government agencies for other purposes, an animal care protocol was not required as per Canadian Council on Animal Care policies (Canadian Council on Animal Care 2020).

DNA was isolated from dried epithelial tissue scraped off teeth onto a fresh piece of wax paper using a sterile scalpel. Multiple scalpels were used in rotation; between samples, scalpels were soaked in 10% bleach for a minimum of 60 min, dipped in 100% ethanol, rinsed with distilled water, and sterilized over a flame. Dried tissue transferred to a 1.5 ml microcentrifuge tube and stored at -40°C. DNA was extracted using a DNeasy 96 Blood and Tissue Kit or a standard DNeasy Blood and Tissue Kit (Qiagen) following the manufacturer's recommended protocols, with the exception that samples were incubated in the proteinase K solution for 72 hrs to digest. Samples were vortexed once every 24 hrs, and any tissue samples that were not fully digested had an additional 10 µl of Proteinase K solution added and were incubated at 57°C for an additional 24 hrs.

Polymerase Chain Reactions (PCRs) and microsatellite genotyping were conducted in the Natural Resources Wildlife DNA Profiling and Forensic Centre at Trent University. Primers for a suite of 15 microsatellites (G10C, G1A, G10B, G1D, G10L, MU05, G10H, MU50, G10P, G10U, MU59, G10M, MSUT6, G10J, G10X) were used to amplify DNA in two sets of pooled multiplexed PCRs as per Crompton *et al.* (2008) which also provides original references for these primers. Additionally, primers SE47 and SE48 were used to determine sex (Yamamoto *et al.* 2002). PCR products were genotyped using a 48-capillary ABI 3730 DNA analyzer.

Data Analysis

To identify microsatellite loci with a high frequency of null alleles (i.e., microsatellite alleles that do not PCR-amplify to a detectable level), the data set was visually inspected for loci with a high level of homozygosity as well as low amplification success. Additionally, the program Cervus was used to estimate the frequency of null alleles for each locus (Kalinowski *et al.* 2007). Cervus was also used to estimate polymorphic information content (PIC) for each locus. PIC, which can range from 0 to 1, measures how variable, and therefore how useful, a microsatellite locus is for population genetic studies (Roy *et al.* 2023). Last, Cervus was used to estimate the probability of identity (PID),

which is the average probability a genotype at a given locus is identical between two unrelated individuals, as well as the more conservative PIDsib, which is the average probability that a genotype at a given locus is identical between full siblings.

Several assessments of black bear population structure were conducted. These consisted of testing for Hardy-Weinberg equilibrium (HWE) within the entire data set as well as within Nova Scotia and New Brunswick separately; using a Bayesian clustering method to detect population genetic structure by grouping individuals in a way that maximizes agreement with Hardy-Weinberg expectations; and conducting an isolation by distance (IBD) test to assess the effect of geographic distance on genetic differentiation across Nova Scotia as well as across Nova Scotia and New Brunswick. Details of each of these analyses are provided below.

The Hardy Weinberg Exact Test from Genepop v. 4.2 (Rousset 2008) was used to estimate HWE within the entire data set, as well as within Nova Scotia and New Brunswick, respectively, using the Probability Test sub-option. Default settings were used for the Markov Chain parameters to estimate an unbiased p-value for the HWE test using the Fisher Method (Guo and Thompson 1992).

The Bayesian clustering program STRUCTURE 2.3.4 (Pritchard *et al.* 2000) was used to detect genetic sub-structuring within the microsatellite data set. The STRUCTURE program was run assuming admixture with a Burnin Period Length of 100 000 and 100 000 Markov Chain Monte Carlo (MCMC) repetitions for values of K=1 to 10 with 10 iterations and the Allele Frequencies Correlated Model option was selected as well. Two related methods were used to determine the most likely number (K) of genetic subpopulations within the data set. The first method assessed when Ln P(D), i.e., the log of the posterior probability of the data, began to stabilize for each value of K (Pritchard *et al.* 2010). The second method, which assesses the rate of change in the log of the posterior probability of the data between successive K values (Evanno *et al.* 2005), was implemented through the Structure Harvester web interface (Earl 2012).

Once the most probable K value was determined, the 10 iterations of those runs were uploaded onto the CLUMPAK web interface (Kopelman *et al.* 2015) to create a single standardized result set. This set was then imported into R (R Core Team 2017) in which the final q matrix (where q is the probability of an individual belonging to a given

genetic subpopulation) was constructed using ggplot2 (Wickham 2016). The ggplot2 package was then used to create a plot of county- and WMZ-level proportions of the likelihood of genetic subpopulations on a geographical map of Nova Scotia and New Brunswick. Individuals were assigned to their most probable K population as in Pelletier *et al.* (2012). Following their methodology, various values of q threshold (i.e., the threshold of probability to assign an individual to a K population) were assessed. The ideal q threshold was chosen with the goal of: (1) weighing the number of individuals that were unable to be assigned to any of the K populations because their q values for each K population were below the q threshold, and (2) maintaining accurate assignment likelihoods, such that the general pattern of K assignment does not change from the original pattern. Values for q of 0.9, 0.8, 0.7, and 0.6 were evaluated. The number of individuals unassigned at each assignment threshold was counted. Plots of q values at each threshold were constructed to assess whether there were any major deviations in K patterning at the various threshold values. Additionally, Chi-squared tests were performed to test for significant changes in proportions of K assignment among the different threshold values. When the appropriate threshold was chosen, a geographical plot was created using ggplot2 to depict the genetic subpopulations on an individual level. Upon completion of the ggplot2 analysis, it was determined that Halifax County was a meeting area of two genetic subpopulations. Because of this, in cases for which more detailed geographic information was available, precise coordinates were used to map individual black bears in Halifax County to further clarify genetic patterning in this region.

Finally, the program Adegenet in R was used to investigate Isolation-by-Distance (IBD) using a Mantel test with 999 Monte-Carlo repetitions. The genetic distance matrices were calculated using pairwise Euclidean genetic distance. Geographic matrices consisted of pairwise linear geographic distances. This was performed at the county level for both mainland Nova Scotia, as well as for mainland Nova Scotia and New Brunswick.

The program FSTAT v. 2.3.9 (Goudet 1995) was used to estimate F_{ST} values between pairs of genetic subpopulations as identified by STRUCTURE. Significance of these values was tested by comparing observed values to values obtained by randomizing alleles throughout the data set mimicking panmixia using 1000 permutations. A Bonferroni

correction was then applied to these tests to account for conducting multiple statistical tests.

For each genetic subpopulation as identified by STRUCTURE, the program GenAIEx v. 6.5 (Peakall and Smouse 2012) was used to calculate the observed (H_O) and expected heterozygosity (H_E) under HWE. Whether H_O and H_E differed significantly was tested in GENEPOP with the Hardy Weinberg Exact Test using the same settings as listed above. FSTAT was used to estimate inbreeding coefficients (F_{IS}), allelic diversity (N_A), and allelic richness (A_R) (Peakall and Smouse 2012). One-sample T-tests were used in R to test if F_{IS} values significantly differed from zero, and a one-way ANOVA and Tukey test were implemented to test if F_{IS} values were significantly different between subpopulations.

Another important and commonly used population-level assessment that was carried out for each genetic subpopulation was estimating its effective population size, N_e, which is useful for predicting the rate of loss of genetic variation in a population (e.g. Pinto *et al.* 2024). N_e was estimated using the program NeEstimator v. 2 (Do *et al.* 2014). The Linkage Disequilibrium-Model with random mating was used as this has been found to be the most robust method when detailed demographic data are unknown (Gilbert and Whitlock 2015). The lowest threshold for allele frequency (P_{CRIT}) used was 0.02 to screen out rare alleles, with confidence intervals calculated using the JackKnife 95% option as per Waples and Do (2008).

RESULTS

Overview of Distribution of Samples

A total of 309 individuals was analyzed for this study; 213 from Nova Scotia and 96 from New Brunswick (Table 1). More samples were collected and processed, however, several degraded samples that had no or five or fewer loci successfully amplify were removed from further analysis. Each of the samples included had at least six loci amplify and the majority (83%) of samples were genotyped for all 14 loci. Due to relatively few specimens from Southwestern Nova Scotia, samples from Yarmouth, Digby, and Shelburne counties were pooled together under 'South Shore.' Similarly, samples from Inverness, Cape Breton, and Victoria counties from Cape Breton Island, Nova Scotia, were pooled together under 'Cape Breton'.

Table 1 **The number of individuals (n) analyzed per location from Nova Scotia counties and New Brunswick Wildlife Management Zones (WMZ); total number analyzed=309.**

Region	Total analyzed	Region	Total analyzed
Nova Scotia	**n**	**New Brunswick**	
Annapolis	13	WMZ7	15
Antigonish	4	WMZ8	15
Cape Breton	1	WMZ9	1
Colchester	25	WMZ11	1
Cumberland	30	WMZ12	30
Digby	6	WMZ13	6
Guysborough	17	WMZ14	10
Halifax	24	WMZ16	4
Hants	15	WMZ17	3
Inverness	2	WMZ18	1
Kings	18	WMZ19	5
Lunenburg	7	WMZ23	1
Pictou	31	WMZ25	4
Queens	10		
Shelburne	1		
Victoria	4		
Yarmouth	5		
SUBTOTAL	**213**	**SUBTOTAL**	**96**

Table 2 **Frequency of null alleles (F(Null)) and polymorphic information content (PIC) of each locus as estimated through Cervus.**

Locus	F(Null)	PIC
G10C	0.052	0.741
G10B	0.050	0.585
G10H	0.048	0.840
G10L	0.028	0.827
MU05	0.034	0.653
G1A	0.039	0.644
G1D	0.027	0.761
G10J	0.057	0.755
G10U	0.067	0.635
MSUT6	0.082	0.635
G10M	0.014	0.778
MU59	0.017	0.720
G10P	0.594	0.828
MU50	0.053	0.837
G10X	0.034	0.866

Upon visual inspection of the data set, locus G10P exhibited high rates of homozygosity as well as relatively low genotyping success. G10P had a considerably larger estimated frequency of null alleles compared to the other loci (Table 2). Because of this, G10P was removed from subsequent analyses. All remaining 13 loci had a mean polymorphic information content (PIC) of 0.740 (Table 2). Genotypes between individual samples had a low probability of being identical ($PID=1.442x10^{-17}$; $PIDsib=5.700x10^{-7}$).

Assessment of Hardy-Weinberg Equilibrium

A significant departure from Hardy-Weinberg equilibrium (HWE) expected genotype frequencies was found for the Nova Scotia samples ($p=3.480x10^{-13}$), as well as for the entire data set ($p=4.990x10^{-11}$). No significant departure from HWE expectations was found for the New Brunswick samples alone (p=0.181).

Bayesian Clustering, Isolation by Distance, and Genetic Differentiation as Assessed by F_{ST}

A plot of Ln P(D) values over runs of K=1 to 10 showed leveling out of the curve at K=3 (Fig 1). Additionally, K=3 had the largest delta K value using the Evanno method (Fig 2), consistent with three genetic

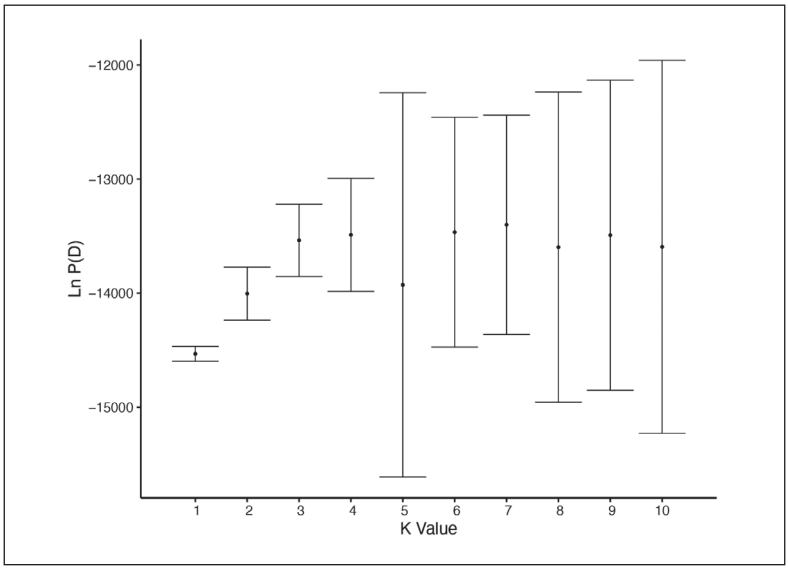


Fig 1 **Average Ln P(D) over values of *K*=1-10. Error bars are variances as calculated through STRUCTURE.**

subpopulations in the data set. When the qplot was examined for the data set at K=3, a large proportion of individuals showed strong assignment likelihoods (Fig 3). The three genetic subpopulations among these samples were New Brunswick, Northeastern Nova Scotia (NENS), and Southwestern Nova Scotia (SWNS) (Fig 4). The haplotype composition of the Cape Breton samples was also seemingly distinct from the adjacent mainland. Unfortunately, only a total of seven samples from across three counties - Inverness, Cape Breton and Victoria – were available for analysis.

When assigning individuals to genetic subpopulations at a threshold of q=0.9, 70 individuals could not be confidently assigned to any genetic subpopulation with this high degree probability. At q=0.8, 42 individuals were excluded. At q=0.7, 26 individuals were excluded, and at q=0.6, 16 individuals were excluded. When q plots for these different thresholds were compared, patterns of K assignment are similar (Fig 5).

No significant changes in K proportions were found among the different thresholds (K1.: X^2=0.098, df=6, p=1; K2: X^2=0.098, df=6, p=1; K3: X^2=0.099, df=6, p=1). Because there were no significant differences in assignment patterning or proportions of each K subpopulation, q=0.6 was chosen to represent this sample set (Fig 6).

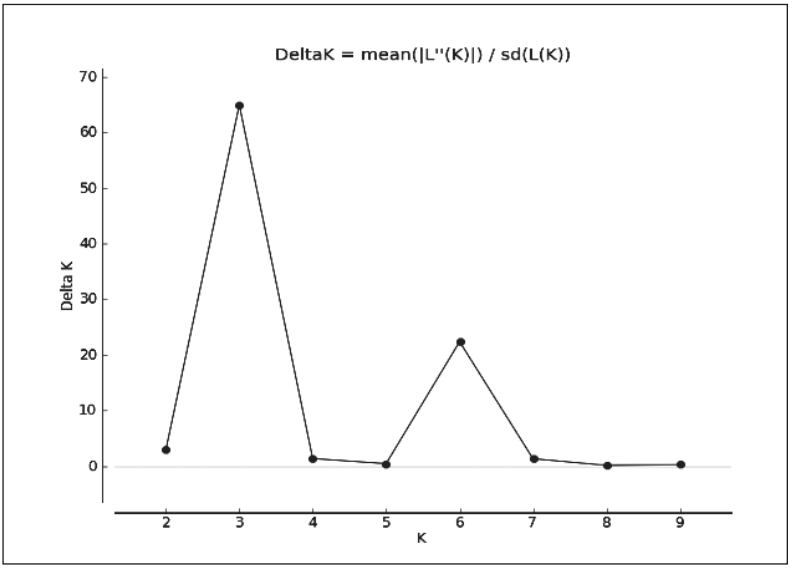


Fig 2 Probability of number of distinct subpopulations (K value) from 1-10 as calculated by the Evanno method with highest delta K at K=3.

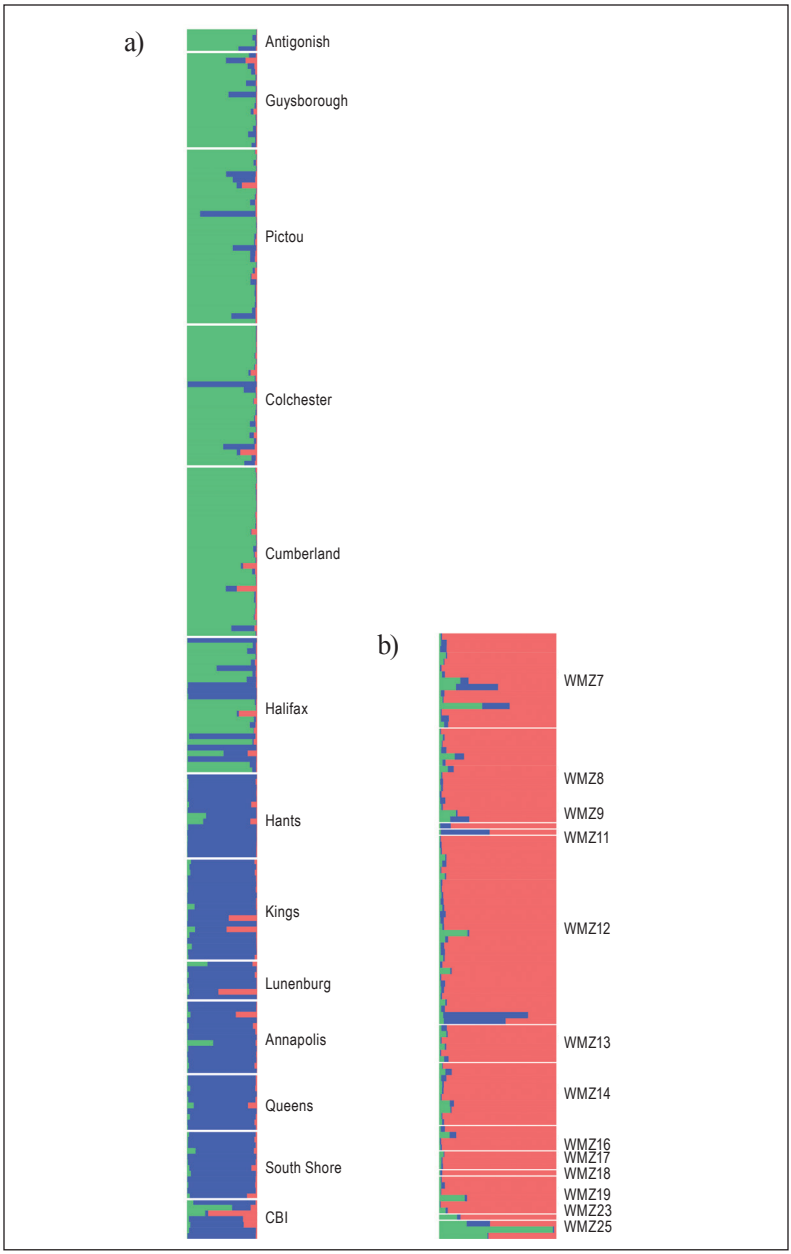


Fig 3 **Final qplot for all 309 samples for *K*=3; each individual is on the inverted x-axis and their relative likelihoods of belonging to each *K* is depicted with red, green, and blue. Pane a) shows results for Nova Scotia. Pane b) shows results for New Brunswick.**

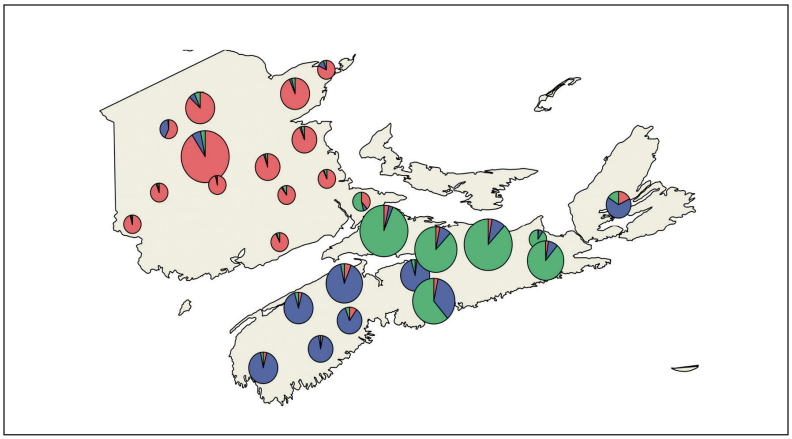


Fig 4 **Geographical map of the Maritimes showing the pie charts of the relative proportion of probable *K* population for individuals within a region (county/WMZ). Pie chart size is proportional to the number of samples from that region.**

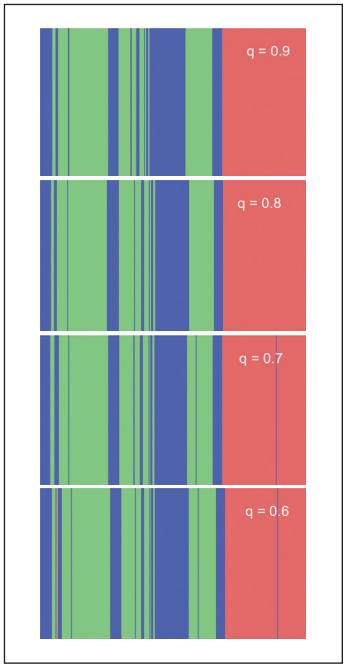


Fig 5 **Pattern of *K* assignment for individuals (x-axis) at various assignment thresholds (q=0.9, 0.8, 0.7, and 0.6). The general pattern of assignments is consistent across all threshold values as well as the proportion of individuals assigned per subpopulation for each *K* value.**

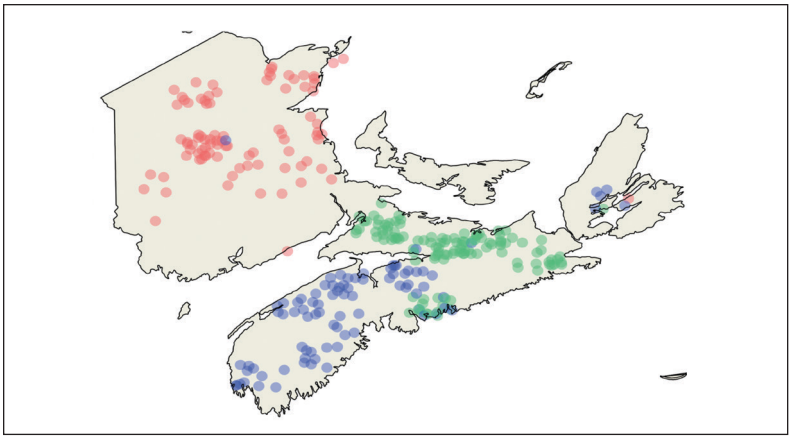


Fig 6 **Individual black bears plotted with their assigned *K* population at a threshold of q=0.6. Overlapping points are jittered slightly so that each can be seen.**

As such, the 16 individuals that were unable to be confidently assigned to a genetic subpopulation were excluded from subsequent subpopulation assessments.

Evidence for a significant positive correlation between genetic distance and geographic distance was found across Nova Scotia and New Brunswick (Fig 7a; r=0.192, p=0.001), as well as across counties of mainland Nova Scotia (Fig 7b; r=0.183, p=0.001).

Pairwise F_{ST} values between each genetic subpopulation were fairly similar, and all above 0.05 (Table 3). All pairwise comparisons were found to be significantly different than if individuals were randomly distributed ($p < 0.05$), and all comparisons were significantly different after Bonferroni corrections.

Genetic Diversity and Effective Population Size (N_e)

The predominantly New Brunswick (NB) genetic subpopulation as identified by STRUCTURE had the largest allelic diversity and richness of all three (Table 4). The NB genetic subpopulation also had the highest observed heterozygosity (Ho=0.77±0.02), which was not found to significantly differ from its expected heterozygosity (He=0.78±0.02; p=0.529). Observed heterozygosities were about 10% lower for both Nova Scotian subpopulations than for New Brunswick (Table 4). For both Nova Scotian subpopulations, Ho and He significantly differed (SWNS: p=0.004; NENS: p=0.045). Both Nova Scotian subpopulations also demonstrated lower allelic diversity and richness compared to

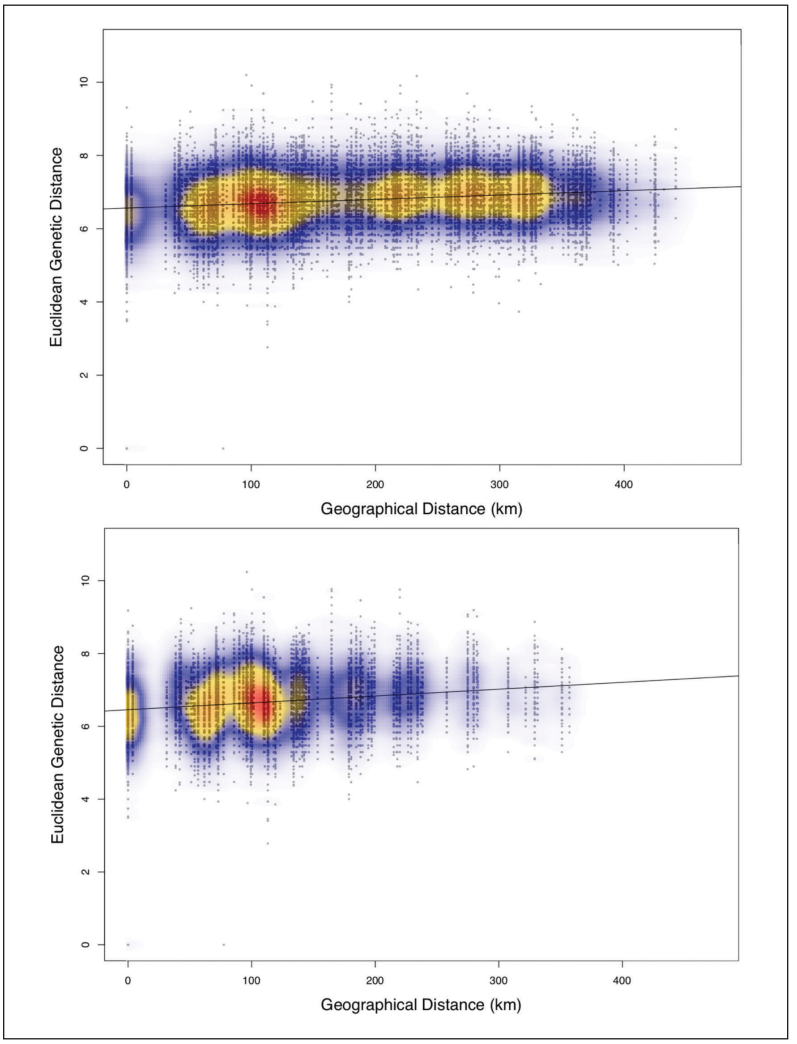


Fig 7 **Euclidean pairwise genetic distance over geographic pairwise distance for individuals in mainland Nova Scotia and New Brunswick (upper panel; r=0.192, p=0.001) and mainland Nova Scotia alone (lower panel; r=0.183, p=0.001). The different colours indicate density of points with red being most dense and blue being least dense.**

the New Brunswick subpopulation. The NB genetic subpopulation had the lowest inbreeding coefficient (FIS) and the SW NS subpopulation had the largest (Table 4). The only subpopulation whose FIS value significantly differed from zero was the SWNS subpopulation (p=0.003).

Table 3 **Pairwise FST values between each pair of genetic subpopulations are found below the diagonal. Above the diagonal, '**' indicates pairs with significant differences after Bonferroni correction.**

	New Brunswick	Northeast Nova Scotia	Southeast Nova Scotia
New Brunswick	-	**	**
Northeast Nova Scotia	0.055	-	**
Southeast Nova Scotia	0.061	0.085	-

** indicates pairs with significant differences after Bonferroni correction.

Table 4 **Number of individuals assigned to each genetic subpopulation (n), observed (Ho) and expected heterozygosity (He), mean number of alleles per locus (NA), allelic richness (A), and inbreeding coefficient (FIS) for each genetic subpopulation with 95% confidence intervals.**

Variable	New Brunswick	N.E. Nova Scotia	S.W. Nova Scotia
n	89	117	87
H_o	0.773±0.021	0.670±0.043	0.687±0.022
H_e	0.781±0.019	0.685±0.044	0.736±0.017
N_A	9.500±1.800	7.143±1.480	6.643±0.910
A_r	9.426±1.741	6.907±1.463	6.616±0.907
F_{IS}	0.015±0.032	0.023±0.023	0.073±0.039

The ANOVA and Tukey tests indicated that the only two subpopulations whose FIS values significantly differed were the NB and SWNS subpopulation (p=0.044).

The New Brunswick subpopulation had the largest effective population size (N_e=551.2 (212.1-infinity)), followed by the Northeastern Nova Scotia subpopulation (N_e=145.4 (101.6-233.8)), and lastly the Southwestern Nova Scotia subpopulation (Ne=76.8 (46.3-152.2)).

Examination of a possible subpopulation divide in Halifax County

Of the 19 hunters and trappers contacted (some had multiple bears), eight supplied detailed GPS information for 10 black bears caught in Halifax County. Two of these bears were unassigned at q=0.6 and thus not included. All samples found north of the City of Halifax belonged to the predominantly NENS genetic subpopulation, whereas samples found south of the city belonged to the predominantly SWNS genetic subpopulation (Fig 8).

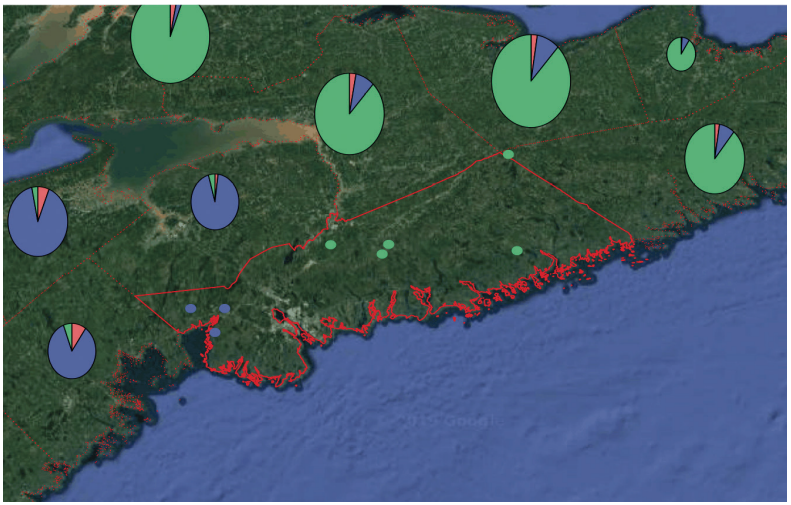


Fig 8 **Individual black bears plotted within Halifax County coloured according to their assigned K population at a threshold of q = 0.6. These points were jittered so that overlapping points could be seen. Surrounding counties have a pie chart of their relative proportions of probabilities for individuals to be assigned to each K population. Pie chart size is proportional to the sample size from that county.**

DISCUSSION

Subpopulations and Patterns of Differentiation

Overview of population structure – This study found evidence of three genetic subpopulations of black bears in the Maritimes with their generalized geographic distributions being (1) New Brunswick, (2) Northeast Nova Scotia, and (3) Southwest Nova Scotia. This finding was supported by STRUCTURE analyses, as well as by Hardy-Weinberg equilibrium assessments that indicated a deviation from HWE across the Maritimes, as well as within Nova Scotia, but not in New Brunswick. With F_{ST} values above 0.05 and below 0.15, these subpopulations exhibited a low to moderate degree of genetic differentiation from one another based on classic interpretations of population genetic structure, as described in Hartl and Clark (1997). These FST values are higher than findings in studies of black bear populations that are connected by mostly continuous habitats (e.g. Northern Ontario, FST=0.0075, Pelletier *et al.* 2012, Newfoundland, FST<0.04, Marshall *et al.* 2011), however they are lower than between some populations separated by anthropogenic barriers (e.g. Florida, FST=0.24, Dixon

et al. 2007, Alabama, F_{ST}=0.20-0.57, Draper *et al.* 2017, Graham 2016, Georgia, F_{ST}=0.14-0.32, Hooker *et al.* 2019), geographical barriers (e.g. Southeast Alaska, F_{ST}>0.12, Peacock 2004, Peacock *et al.* 2007), or a mix of both (e.g. Ontario, F_{ST}=0.14, Pelletier *et al.* 2012). This low degree of differentiation indicates that there is sufficient gene flow to prevent strong differentiation across the Maritimes. Alternatively, the low level of differentiation observed reflect the fact that existing barriers between subpopulations are relatively recent. For example, Proctor *et al.* (2016) found low dispersal rates of black bears across a highway despite little genetic differentiation between black bears on either side. This result is an important consideration in the Maritimes given that the human population of Nova Scotia has doubled in only the last 100 years, bringing with it increased infrastructure (Canada 2013). This situation is especially true within the Halifax Regional Municipality, near where the NENS and SWNS subpopulation meet.

New Brunswick Subpopulation – The New Brunswick subpopulation had a higher allelic diversity than other black bear populations reported to date in the literature. The New Brunswick subpopulation also demonstrated relatively high observed heterozygosity (H_O=0.773±0.021), consistent with populations that exist in continuous forested habitats (Paetkau and Strobeck 1994, Pelletier *et al.* 2012, Sawaya *et al.* 2014). The expected and observed heterozygosities were not found to significantly differ, indicating a stable level of heterozygosity. Additionally, this subpopulation had an inbreeding coefficient that was not found to significantly differ from zero indicating more or less randomized mating within this subpopulation (Keller 2002). The New Brunswick subpopulation had the largest effective population size (N_e) of all three subpopulations in the Maritimes and was the only one of the three within the recommended minimum N_e for a sustainable population (N_e=500-1000, Franklin and Frankham 1998, Lynch and Lande 1998, Ryman *et al.* 2019). The infinite upper limit of its confidence interval is consistent with other large populations that do not appear to be experiencing strong genetic drift. In terms of interpreting the potential "infinite" estimate of numbers for this population, it is important to note that NeEstimator works best for estimating N_e in small populations in which the signal for genetic drift is large (Waples and Do 2010). Collectively, this evidence indicates that the New Brunswick subpopulation of black bears exhibits high genetic variability, an adequate level of connectivity, and that it has a reasonably large (but obviously not infinite) effective

population size. Such a subpopulation is likely at a low risk for extirpation from population-genetic related parameters (e.g. loss of allelic variation, low heterozygosity, inbreeding, etc.).

Northeast Nova Scotia Subpopulation – The Northeast Nova Scotia subpopulation had a fairly high allelic diversity and richness compared to other black bear populations, however, it had approximately 10% lower observed heterozygosity than the New Brunswick subpopulation (H_O=0.670±0.043). The difference between H_E and H_O was found to be significantly different, indicating an excess of homozygosity in this subpopulation, which could be caused by genetic drift or inbreeding. This subpopulation, however, was not found to have an F_{IS} value significantly different from zero. The Northeast Nova Scotia subpopulation had the second largest N_e estimate of the three subpopulations; however, it was almost 75% smaller than that of the New Brunswick subpopulation. The N_e estimate was far below the recommended size for long-term conservation ($N_e \geq 500$), however, it was within an acceptable range for short term conservation ($N_e > 50$, Ryman *et al.* 2019). Populations with N_e values in this range are expected to lose genetic diversity over time through drift, however, at fairly slow rates. The N_e estimate for the Northeast Nova Scotia subpopulation was similar to the one found for black bears in eastern Utah that had fairly low genetic diversity levels (N_e=142-222 calculated using two different methods by Sinclair *et al.* 2003). This result likely indicates that genetic drift has significantly affected genetic diversity of black bears in NENS. In all, these findings indicate the NENS black bear population is viable and likely at a low risk for extirpation; however, the subpopulation should be monitored to prevent further loss of genetic diversity.

Southwest Nova Scotia Subpopulation – The Southwest Nova Scotia subpopulation had the lowest allelic diversity and richness of all three Maritime subpopulations. Although this subpopulation had a similar observed heterozygosity as the Northeast subpopulation, it had a larger significant difference from its expected heterozygosity. This indicates a greater homozygote excess in comparison to the NENS subpopulation. This subpopulation had the largest F_{IS} value, and the only F_{IS} value significantly larger than zero. With an F_{IS} value similar or larger to values found in disjunct black bear populations (Arizona, F_{IS}=0.038-0.110) (Varas-Nelson 2010), it is probable that inbreeding is a contributing factor to reduced heterozygosity in this region. The N_e

estimate for black bears in this subpopulation was about half of that of the Northeast Nova Scotia subpopulation, N_e=76.8 (47.3-152.2). Although not quite as low as severely disjunct black bear populations (e.g. Mobile River Basin, N_e=31 (20.5-47.4) or Northeastern Alabama, N_e=3.4 (2.8-4.8)(Draper *et al.* 2017), this finding indicates strong effects of genetic drift and/or inbreeding in the black bears of SWNS. Together, these findings point to this subpopulation having experiemced a loss of genetic diversity both in allelic variation and heterozygosity. This is particularly interesting as black bear density was estimated to be highest in the southwest portion of the province (Pulsifer *et al.* nd.), indicating the SWNS subpopulation should have a comparatively large census size. Having a large number of individuals should help minimize effects of genetic drift. These findings indicate a need to closely monitor this subpopulation and further investigate drivers of genetic diversity loss.

Drivers of Genetic Differentiation

Nova Scotia vs. New Brunswick – As important as it is to delineate genetic subpopulations in wildlife studies, it is also important to understand what the drivers of genetic differentiation are between them (Pelletier *et al.* 2012). Genetic differentiation across black bear populations in continuous habitats tends to be largely driven by distance, following the isolation by distance (IBD) pattern (e.g., r=0.552, p=0.002). Across the Maritimes, a weak but significant signature of IBD between black bears was detected (r=0.192, p=0.001). This is a similar degree of correlation in IBD as found in the study by Pelletier *et al.* (2012) when the isolated population of black bears on Bruce Peninsula was included in their IBD assessment (r=0.161, p=0.002). This suggests that across the Maritimes, IBD can account for some, but not all, of the observed genetic differentiation among black bears. According to the STRUCTURE analysis, the New Brunswick and NENS subpopulations geographically meet on the western side of the Isthmus of Chignecto. This finding is consistent with the hypothesis that black bear dispersal is compromised between these provinces due to the natural geography and possibly anthropogenic barriers to black bear dispersal associated with the Isthmus of Chignecto. A future study with a more extensive and even-sized sample set from both sides of this divide, as well as samples with known GPS-coordinates would be beneficial to help delineate potential landscape features contributing to this genetic divide.

Northeast vs. Southwest Nova Scotia – IBD seems to play a similar role across the mainland of Nova Scotia compared to between Nova Scotia and New Brunswick (r=0.183, p=0.001). This result suggests that IBD accounts for some but not all of the genetic structure within the province. Additionally, STRUCTURE analysis indicated the two Nova Scotian subpopulations' geographic boundary bisected the province into northeast and southwest regions. To further investigate what may be contributing to this genetic divide, it can be helpful to consider important features found at the subpopulation boundary. Hants and Colchester counties are found along the western portion of this boundary. Black bears in Hants County were found to predominately belong to the SWNS subpopulation, whereas black bears in Colchester County were found to predominately belong to the NENS subpopulation. This fairly clear divide indicated that the black bear subpopulation genetic differentiation roughly follows the political divide between these two counties, which in turn follows the Shubenacadie River, with notably powerful tides and currents (e.g. Rulifson and Tull 1999). Additionally, these counties are divided in part by Highway 102, which is currently one of the busiest roads in the Maritimes (Nova Scotia Department of Public Works 2023). Highways have been shown to act as dispersal barriers for black bear populations (Whittle 2009, Sawaya *et al.* 2014, Proctor *et al.* 2016). Even before Highway 102 was completed, there was a series of high-traffic, secondary highways that similarly intersected this part of the province. One or both these factors (i.e., highways and waterways) are likely contributing to the population structure on the western portion of this genetic boundary.

Along the eastern side of the boundary is Halifax County, which includes the Halifax Regional Municipality, the most urbanized region of the province (Government of Canada, Statistics Canada 2017). The northern portion of this county, however, is largely forested. STRUCTURE analysis indicated that a large proportion of individuals within Halifax County had high assignment likelihoods to either the Northeast Nova Scotia or Southwest Nova Scotia subpopulation, with a couple admixed individuals. This led to the hypothesis that the subpopulation delineations were somewhere within the county. The closer analysis performed using corrected GPS-coordinates in Halifax County revealed that individuals assigned to the Northeast subpopulation were only found north of the city of Halifax, and individuals assigned to the Southwest subpopulation were only found

south of the city. This pattern suggests the city of Halifax is a barrier to black bear dispersal on the eastern portion of this genetic boundary, supported by the fact that black bears have been found to avoid urban zones (Whittle 2009).

It is also possible that the Strait of Canso that separates Cape Breton Island from mainland Nova Scotia was an historic barrier to gene flow in the northeastern region of the province. Analysis of additional samples from Cape Breton is certainly warranted based on apparent haplotype frequency differences in the present samples.

General Implications Regarding the Population Structure of Black Bears in Nova Scotia

There is no recent estimate of black bear densities or population census for Nova Scotia (Airst and Fleming 2024). The New Brunswick Department of Natural Resources Minister estimated the census population for that province at ~16 500 a decade ago (CBC 2014), which corresponds to a density of ~0.22/km. If this value is similar for Nova Scotia, there would be ~12 000 black bears in this province. From data presented in Fudge *et al.* (2007), which included co-authors from the Nova Scotia Department of Natural Resources, the Nova Scotia black bear census population was ~6 000 at that time. Using these two values (6 000 to 12 000) as a general range, black bears in Nova Scotia would have an effective population size/census population size (i.e., N_e/N_c) of 0.019-0.037 (when combining N_e estimates from Northeast and Southwest subpopulations). Most wildlife populations have a ratio of about 0.1 (Frankham 1995). This is a strong indication that genetic drift has had a notable effect on genetic variation in black bears in Nova Scotia. This ratio could also be an indication of an historic bottleneck event (Luikart *et al.* 2010), which could have been caused by the largely unregulated historical harvest of black bears in the region until the late 1990s (Nette 1994), or potentially by the division of a formerly panmictic population into subpopulations through anthropogenic development. Moving forward, it will be important to monitor this relatively low N_e value for black bears in Nova Scotia so that measures can be taken to mitigate loss of genetic variation.

To further investigate the various potential factors contributing to the population genetic structure of black bears in Nova Scotia, it would be informative to examine variation in mtDNA. Because mtDNA is maternally inherited, is nonrecombining and evolves at a generally

predictable rate, analyzing this molecular marker would be useful to help understand how long these subpopulations have existed and to assess whether anthropogenic land conversion has been an important factor in determining their current structure (e.g. Shafer *et al.* 2011). Additionally, obtaining precise GPS coordinates for samples in the future may allow the identification of particular landscape features creating dispersal barriers for black bears (Proctor *et al.* 2016). Detailed GPS data proved useful to a degree in the Halifax County level investigation, however, this analysis only included eight individuals. Finally, it would be beneficial in future to study the black bear population structure on Cape Breton Island. Only seven samples were collected from Cape Breton Island for this study, and thus it is inappropriate to draw conclusions regarding black bear population genetics in that region at present.

Management Implications

Divergence between subpopulations in nuclear-encoded genes can reflect the effects of natural selection and thus may signify distinct, ecologically functional units within a species (Moritz 1994). Thus, the delineation of genetic subpopulations can be useful for wildlife management officials to construct ecologically relevant Management Units (MUs). By constructing MUs of a species using subpopulation boundaries, the specific needs of each subpopulation can be addressed. For example, it could be beneficial for black bears on mainland Nova Scotia to be managed separately in NENS from SWNS if the Shubenacadie Canal system is a partial geographic barrier slowing the rate of gene flow between these regions. It would be particularly beneficial to increase monitoring of black bears in SWNS which are exhibiting lower levels of genetic diversity, and to implement management strategies aimed at ensuring no further loss of genetic diversity occurs in this subpopulation.

Acknowledgements For logistical and infrastructure support we thank the staff at the Nova Scotia Department of Natural Resources and in particular, former wildlife biologist Mike Boudreau. We thank Drs. Aaron Shafer and Stephen Petersen, as well as the late Dr. Steve Mockford, for helpful discussions about population genetic analyses. (That said, any errors in interpretation are ours!) We thank Colleen Booth and Hilary Roberts helping with field work. Thanks also to Eric

Sullivan and Kevin Craig from the New Brunswick Department of Natural Resources and Energy Development for providing black bear teeth from that province. We thank the many hunters and trappers who provided the black bear teeth used in this study and those who provided more detailed information on where their samples were collected in Halifax County. We thank Dr. Graham Forbes and an anonymous reviewer for helpful editorial suggestions to an earlier version of this manuscript. This work was funded by Nova Scotia Habitat Conservation Fund grants to DTS and SB-N, by an NSERC Discovery Grant to DTS, by a Raddall Research Fund Award to DTS, and by a Nova Scotia Provincial Graduate Scholarship, the Emma Tichenor Memorial Award, and the David Cartwright and Cyril Coldwell Memorial Award to BS.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 607-611

STUDENT PAPER

MOUTH-BRAIN CONNECTION: EXPLORING HOW ORAL BACTERIA AFFECT BRAIN HEALTH

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Oral health is connected to brain health. Recent studies suggest that infectious bacteria found in the mouth and oral tract may have a direct relation to the health of our brains. These microorganisms have been connected to the occurrence and progression of cognitive dysfunction and disease. Microorganisms in the oral cavity are linked to neuro degenerative disease, such as Alzheimer's because they can migrate to the central nervous system, cause inflammation, and alter the formation of Proteins.

According to the Canadian Dental Association (2017), 7 out of 10 Canadians will, at some point, develop gum disease. Additionally, the Alzheimer's Society of Canada (2024) estimates that around 771,939 people in Canada are living with dementia, Alzheimer's disease being its leading cause. Now the real question is, how do these relate? Or do they even relate at all?

Gum disease is subtle yet destructive. According to the Centers for Disease Control and Prevention (2024), the most common gum diseases are gingivitis and chronic periodontitis (CP). Both issues occur when an over accumulation of bacterial biofilms (dental plaque) sit where the teeth meet the gingiva (Gums). Gingivitis is a mild case of gum disease caused by the accumulation of oral bacteria on the tooth. At this stage of gum disease, the bacteria adhering to the tooth's surface has formed plaque. Neglecting plaque can result in the formation of calculus, a mineralized form of plaque that can only be removed by professionals. The presence of calculus near the gum line will result in swollen gums and irritation or bleeding while brushing and flossing. In the progression and later stages of gingivitis, swelling and infection prompt the reproduction of a more pathogenic bacteria known as *Porphyromonas gingivalis* (*P. gingivalis*). CP is often the result of untreated gingivitis and the reproduction of *P. gingivalis* beneath

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the gum line along with the presence of calculus. CP occurs when the infection moves below the gum line and begins to attack vital tooth structures such as the periodontal ligament and bone, both of which are responsible for tooth stability. This can cause gum recession, pocket formation, (which encourages further infection) and eventually the loss of teeth (Wilson and Wilson 2021).

Alzheimer's disease (AD) remains an active area of research for scientists in an attempt to understand its main cause and how to prevent its progression. Generally speaking, AD can be characterized by the buildup of plaques and tangles within the brain, leading to disturbance between neuron communication, and thus causing nerve damage. This results in a gradual decline of brain tissue known as atrophy, which is directly related to memory loss, alteration in personality and the hindrance in one's ability to perform physical activities (Braak, Griffing, Arai and Braak 1999). Thousands of Canadians suffer from the symptoms and consequences that come with this neurodegenerative disease (Alzheimer Society of Canada 2024) and their families are forced to watch their loved ones slowly lose what makes them who they are. The need to understand this disease and discover ways to prevent it is self-evident.

Recent studies have proven that oral bacteria can migrate from the mouth to the central nervous system. Though many bacteria fail to reach the brain due to its highly specialized defence wall known as the blood brain barrier (BBB), some microorganisms have developed mechanisms to cross this barrier (Coureuil *et al*. 2017). Kerstens *et al*. (2024) explains that bacteria which originated in the oral cavity have been detected in the bloodstream after gum manipulation. Stimulation such as flossing, tooth brushing, or dental procedures in which the gums or oral surfaces experience minor abrasions, allow bacteria to enter the bloodstream. In fact, microbes such as *P. gingivalis* and its outer membrane known as Lipopolysaccharide (LPS) have been found in the brains of AD patients (Narengaowa *et al*. 2021). This does not suggest the abandonment of procedures which may disrupt the gums as even the consumption of hard foods or unrelated injury provide a similar window for bacteria to enter the blood stream, rather, this suggests the importance of maintaining a healthy oral microbiome to avoid complications. Lipid A in LPS acts as the bacterium's main source of pathology, often triggering immune responses like pro-inflammatory

cytokines from the host, resulting in damage to surrounding tissues (Alexander and Rietschel 2001).

A study by Wu *et al*. (2017) performed on mice found that the LPS from *P. gingivalis* can induce biochemical reactions within the brain, causing numerous malfunctions for neuronal health and longevity. Neurons are responsible for sending signals, while glial cells act as protection and support. When foreign microorganisms like *P. gingivalis* enter the brain, the glial cells react to the bacteria as a threat. They signal pro-inflammatory molecules known as cytokines to the location in order to prevent the spread of bacteria and recruit other immune cells. Neuroinflammation plays a huge role in neurodegeneration, cognitive dysfunction and even nerve cell death (necrosis) (Narengaowa *et al*. 2021). Interestingly, research suggests that although dementia and its mechanisms are not fully understood, inflammation plays a major role in its development and progression (Guo *et al*. 2021).

Chronic inflammation in the brain can promote the over production of naturally occurring proteins such as Amyloid-beta (Aβ) and tau, resulting in the formation of neurodegenerative substances. Researchers hypothesise that the presence of bacteria such as *P. gingivalis* in the brain can stimulate the overproduction of Aβ (Zhao *et al*. 2023). *P. gingivalis* has been found to induce excess production of Aβ which forms a sticky plaque-like residue between the neurons. Ironically, much like the plaque on our teeth, Aβ must be regularly maintained in order to avoid damage to the brain and neuronal health. Glial cells are responsible for the management of this, and so, when bacteria signal the overproduction of plaque, glial cells respond and it can lead to severe inflammation.

Similar to the Aβ's response to oral bacteria in the brain, tau proteins may be influenced by the presence of oral bacteria. Tau is a protein that stabilises microtubules, which act as intracellular transport structures within neurons. Zhao *et al*. (2023) suggest that the translocation of oral microorganisms from the mouth into the brain can be linked to tau hyperphosphorylation, a process in which tau proteins form abnormally, detaching themselves from the microtubules and instead, stick together, forming tau tangles. Wozniak *et al*. (2009) states that "neurofibrillary (tau) tangles are one of the main neuro pathological features of Alzheimer's disease". These tangles are associated with disrupted intracellular transport and neuronal dysfunction, which contributes to neurodegenerative processes. Ultimately, the hindrance

of the tau proteins in the brain by oral bacteria may play a role in mechanisms involved in Alzheimer's disease progression.

In conclusion, it is clear that oral bacteria do indeed play a role in the health of our brains. The effects of these microorganisms match with the characteristics of cognitive dysfunctional diseases such as Alzheimer's. The migration of microorganisms through the bloodstream and into the brain is the beginning of brain altering reactions like the immune response of inflammation, the overproduction of Aβ causing plaque build up, and tau tangles. This field has room for exploration, as there are still many questions to answer regarding the relationship between the mouth and brain. How early do these bacteria affect our brains before symptoms appear? Can the damage be reversed? Understanding how the microorganisms in the mouth affect the brain is important because it may introduce new ways to slow down or prevent the onset of neurodegenerative disease. Understanding the oral cavity, the second most diverse microbiome in the body, continues to prove significant beyond its role in digestion, respiration, and speaking. Brushing twice daily and flossing every 24 hours seems to offer more than a healthy smile, rather, keeping up with oral hygiene is an easy way to foster a healthy brain. The efficiency and health of our brain is affected by the management of oral bacteria through good hygiene, so make sure to keep brushing!

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 613-621

STUDENT PAPER

REVOLUTIONIZING MOBILITY: BRAIN COMPUTER INTERFACES AND THEIR APPLICATIONS IN PROSTHETICS

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ABSTRACT

The revolutionary field of brain-computer interfaces (BCIs) and robotic prosthetics offers new hope for restoring independent movement for the disabled. By enabling direct communication between a person's brain signals and external machines, BCIs have demonstrated their ability to interpret brainwaves and execute intended movements. These technologies have empowered individuals who have been immobile for years to regain independence. BCIs have been used to perform tasks such as typing and accurately controlling prosthetics. Through practice and the application of machine learning, BCIs refine their ability to decode brainwave patterns and infer users' intentions. A significant challenge remains in implementing BCIs that can translate high-dimensional, real-time neural data into precise motor commands for prosthetic arms through risky surgery. Despite this, advancements in BCIs and robotic prosthetics hold tremendous potential to dramatically improve the lives of those who have lost the ability to move. The integration of BCIs with prosthetics gives amputees a deeper intuitive connection with their artificial limbs.

INTRODUCTION

Every year, thousands of people suffer from traumatic incidents that result in severe bodily damage, with over one million amputations happening globally every year (Pro Medical East 2023). This can lead to several negative implications on their mental health and severely impairs their daily functioning. Prosthetics have been used for centuries in the form of hook hands and wooden legs, but these substitutes don't provide much connection to the user and do not provide the same level of mobility as their previous limbs. Recent research suggests

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combining prosthetics with BCIs offers profound new possibilities for people who have lost their limbs. BCIs are a collection of technologies that translate the electrical signals from a brain's neural activity into instructions for an external computer or machine. A typical BCI system operates by first collecting neural information, secondly decoding it using an algorithm, and finally performing the intended action with an effector (Vilela and Hochberg 2020). To collect data from the brain, a BCI needs to collect the electrical signals produced by the brain's neural activity (Vidal *et al.* 2016). BCIs use electrodes to capture brain activity, with methods varying from non-invasive electroencephalography (EEG) to invasive electrocorticography (ECoG) each offering differing pros and cons (Choi *et al.* 2018).

EEG is when electrodes are placed onto a user's scalp and record neurological data (Tariq *et al.* 2018). EEG offers a non-invasive method to extract signals from a patient's brain, and is the most widely used because of its practicality, safety, and cost-effectiveness (Orban *et al.* 2022). The other mode of gathering data for BCIs is through electrocorticography, or ECoG (Shih *et al.* 2012). ECoG utilizes an array or grid of electrodes implanted intracranially into a brain. This allows for greater accuracy in data collection (Shih *et al.* 2012). These signals are collected and decoded with machine learning and complex algorithms to produce commands to be carried out by a robotic limb.

In this article, we will investigate different methods of BCI collection, processing and output. We will also look at the practical applications, challenges, implications for society, and the future that BCIs will help create.

BCI METHODS FOR PROSTHETIC CONTROL

There are many ways that BCIs and robotic limbs have been combined. Medical professionals have done this through EEG, ECoG, and intracranial implementations.

Through EEG, data is collected through electrodes placed on the scalp. EEG systems commonly use either wet electrodes, typically silver/silver chloride (Ag/AgCl), which require a conductive gel, or dry electrodes, which do not need gel but often face higher impedance issues (Al-Qahtani *et al.* 2024). There are a few problems with EEG however, as EEG signals are easily distorted through background noise, such as power lines (Shih *et al.* 2012). In general, the closer

the BCI is to the neurological tissue, the more effective it will be. Microcontrollers, including Arduino boards, receive movement commands and adjust motor parameters to control limb direction, speed, and position (Al-Qahtani *et al.* 2024). Alternatively, ECoG utilizes microelectrode arrays, which are tiny needle-like electrodes implanted directly into brain tissue (Raspopovic *et al.* 2014), specifically electrodes approximately 2.3 mm in diameter and 1 cm apart (Miller *et al.* 2020). The ECoG array collects the electrical potential summing from the individual neuron populations from each electrode this allows for greater accuracy in data collection (Miller *et al.* 2020). Using Bluetooth, this data can be transmitted to a computer, like an Arduino (Priya *et al.* 2025), which then interprets brainwave data to produce appropriate movement commands (Al-Qahtani *et al.* 2024).

When comparing EGG and ECoG, the ECoG offers more in terms of signal quality, data reliability, and long-term stability, but is more costly and at risk of surgical implications than the EEG. Several brain signals are utilized by both EEG and ECoG, including P300 EEGs and sensorimotor rhythms (SMRs) (Liu *et al.* 2022). But steady-state visually evoked potentials (SSVEPs), which are natural responses to visual stimuli at specific frequencies, are the preferred brain signal to use. SSVEPs are evoked in the brain when looking at certain objects that flicker at distinct frequencies (Liu *et al.* 2022), and they are the preferred brain wave to use due to their higher signal to noise ratio and the fact that there is no need for initial calibration or learning period for the users (Li *et al.* 2024). The brain responds to these flickers by generating electrical signals that can be detected through EEG. Motor imagery is then used to trigger the selection of a certain task. Signal processing algorithms are employed to decode user intentions from noisy neural data (Moreno-Calderon *et al.* 2023). The acquired signals are then processed using a series of algorithms to decode intentions, like moving a prosthetic limb (Lebedev and Nicolelis 2017). Specifically, EEG signals are processed using feature extraction (CSP – Common Spatial Patterns) and a classifier (QDA – Quadratic Discriminant Analysis) to classify different skills (Aggarwal and Chugh 2019).

Common Spatial Pattern (CSP) is a feature extraction technique widely used in BCIs. CSP provides spatial filters that optimally discriminate between two classes of EEG data in the least-squares sense, this capability translates to higher classification accuracy in motor imagery BCIs (Falzon *et al.* 2012). Channel contributions indicate the

areas of the brain responsible for certain motor imagery tasks, and the classifier then determines the user's choice. Next, this motor imagery is used to control movement. For example, the user imagines moving their hand right, and this is processed through feature extraction using a binary classifier. This determines whether a user is in a rest state or a "move" state and how the user wants to move.

Brain signals are subsequently translated into commands that control motors and actuators in prosthetic devices, allowing complex movements like gripping or fine motor adjustments (Vilela and Hochberg 2020).

APPLICATIONS IN PROSTHETICS

Prosthetics have made significant strides in restoring lost functionality, particularly in sensory feedback for amputees. In the realm of brain-computer interfaces (BCIs), companies like Neuralink are pushing the boundaries of what's possible with neural technology. These companies are working to enable individuals to control prosthetic devices simply by thinking about them, a significant leap toward seamless integration between the human brain and machines (Mullin 2024). Notably, there have been successful applications of BCIs in which paralyzed individuals were able to control robotic arms and gain a sense of touch in their prosthetics, offering hope for those who have lost both mobility and sensation (University of Calgary 2023). BCIs are also playing a crucial role in the development of motor neuroprosthetics. For amputees, electromyographic signals (EMG) from the peripheral nervous system are used to better connect the motor nerves in the residual limb to the prosthetic. This is achieved through surgery, which enhances the pairing between nerves and prosthetic components, resulting in more intuitive limb control (Cogan 2008). These advances ensure that prosthetics are not only functional but also capable of responding to the user's intentions in a more human-like manner.

In addition to prosthetic limbs, non-invasive applications of BCIs are gaining traction. EEG-controlled exosuits, for example, have been shown to assist paralyzed individuals in regaining some degree of mobility (Colucci *et al.* 2022). By interpreting brain signals via EEG, these exosuits can augment movement and assist with activities that would otherwise be impossible for someone with spinal cord injuries. This kind of technology shows promise in facilitating more natural

interactions between individuals and the environments around them, thus improving independence and quality of life.

CHALLENGES

One of the primary challenges related to BCIs is the risk associated with brain surgery, as implantation of electrodes involve invasive procedures that carry potential dangers. These risks include inflammation, tissue scarring, seizure, and hemorrhaging (Shih, Krusienski and Wolpaw 2012). Tissue damage due to surgical implantation can trigger immune responses, leading to inflammation and the formation of scar tissue, which can interfere with the BCI's functionality and cause further damage to the brain (Cogan 2008). Neuroplasticity–the brain's ability to reorganize and form new neural connections–may be altered over time if electrode implants disrupt natural neural pathways or induce changes in brain activity (Shih *et al.* 2012). On the technical side, BCIs face significant material and engineering challenges.

In addition, electrodes used in BCIs are exposed to a hostile environment in the brain, which can lead to corrosion, tissue encapsulation, or mechanical wear. This degradation reduces the quality of the signals detected by the electrodes, leading to a decline in the BCI's performance and necessitating replacement or recalibration of the devices. Additionally, maintaining stable electrical contact between electrodes and neurons in the dynamic environment of the brain is a persistent challenge. The brain's movement and natural shifts in position can disrupt the interface, leading to signal instability and the potential for data loss or misinterpretation (Soangra *et al.* 2023).

Thus, while significant progress has been made in recent years, ongoing research is required to address these biological and technical obstacles to make BCIs a viable and reliable solution for medical and other practical applications.

FUTURE POSSIBILITIES

Humans currently have limited ways of communicating information with devices, with a mouse and a keyboard. But with more BCI advancements, it may be possible to transmit thoughts into computers and have them decode brain signals so that computers can understand humans. Developments in neural engineering and artificial intelligence aim

to create seamless integration between prosthetic limbs and neural commands, improving both user experience and functionality (Lebedev and Nicolelis 2017). One area of growth is the implementation of advanced sensory feedback systems. Currently, most prosthetic devices lack the ability to replicate natural tactile sensations. Future innovations will focus on integrating haptic technologies that provide feedback on touch, pressure, and temperature. This advancement would not only allow users to better interact with their environment but also enhance motor control by enabling more precise grip and manipulation of objects (Kim *et al.* 2018).

The integration of wireless communication technologies will further enhance BCI-controlled prosthetics. Wireless systems enable the seamless transmission of neural commands to robotic limbs without physical connectors, reducing the potential for mechanical failures. Coupled with machine learning algorithms, these systems could adapt to user-specific neural patterns, anticipating intended movements and improving overall control (Shih *et al.* 2012). AI-driven adaptive features may even allow prosthetic devices to self-learn from the user's behavior, enhancing usability over time (Chopra and Emran 2024). Continuing these endeavors will pave the way for BCIs and prosthetics to improve lives meaningfully. Further connection with the human body and machine could break boundaries of what the human body can do.

CONCLUSIONS

Brain-Computer Interfaces (BCIs) and prosthetics offer unprecedented opportunities for enhancing human capabilities and improving quality of life. BCIs come in two primary forms: non-invasive EEG and invasive ECoG. These technologies enable the decoding of brain signals, such as Steady-State Visual Evoked Potentials (SSVEPs), to translate thoughts or intentions into action, offering restored movement and communication for those with severe disabilities. The potential societal implications of BCIs and prosthetics include restoring mobility and function to those with spinal cord injuries or amputations, to augmenting human cognitive or physical abilities for everyday tasks. However, several challenges accompany the development of these technologies. High costs, and safety concerns related to invasive procedures all require careful attention. Future advancements could lead to fully integrated systems that enhance brain function or lead to completely new forms

of human-computer interaction. In my view, BCIs and prosthetics are pivotal in overcoming limitations of physical or cognitive disabilities. Ultimately, BCIs are a developing area of biomedical science that give amputees to regain a feeling that they have lost, autonomous mobility, in a way they never have before.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 623-633

BOOK REVIEWS

The Social Lives of Birds: Flocks, Communes, and Families. **Joan E. Strassmann. 2025. Tarcher, New York, USA. 291 pp. ISBN 978-0-593-85306-1.**

Many of us take great joy in watching birds spend time with one another. I am thinking of flocks of chickadees, nuthatches, kinglets, and woodpeckers foraging in woodlands during winter, summer gatherings of hundreds or even thousands of seabirds forming breeding colonies on coastal islands, and mother ducks keeping watchful eyes over their broods.

Strassmann is a leading authority on sociality among eukaryotes. She takes us on a passionate journey to celebrate what we know about the varied social lives of birds. Each of the book's ten chapters opens with a beautiful illustration and focuses on one of the many types of avian sociality, including flocking and roosting, colonial nesting, lekking courtship behaviour, mate choice and parental care, helping others, and communal nesting. By leaning on perspectives of Darwinian evolution, she clearly explains how cooperation and conflict interact in ways that make it advantageous for birds to behave in seemingly counterintuitive ways. These include joining flocks or communal roosts that may be highly conspicuous to predators, breeding in crowded colonies where nesting neighbours can be aggressive, sharing nests with individuals that reject some eggs laid by nesting mates, quarreling with members of their own family, or helping care for young that are not their own.

This book makes complex social behaviours accessible to all of us. The author masterfully synthesizes the vast body of scientific literature into engaging stories of the social lives of Cliff Swallows, Black Vultures, Greater Sage-grouse, Superb Fairywrens, Pinyon Jays, and those of many other species. References to the nearly 300 scholarly works cited are presented in the final section.

The book is also a great tribute to the many scientists and naturalists who have helped reveal social secrets of birds around the world by conducting decades-long population studies of known individuals and by undertaking thoughtful field experiments. Colourful descriptions of study sites are intertwined with accounts from researchers and

Strassmann's own observations from the field, which in my mind contribute significantly to the fascinating stories that she is telling. *The Social Lives of Birds* is a must-read for all animal behaviour enthusiasts. Its subject matter promises to intrigue even the most seasoned observers of bird sociality.

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***Ocean. Earth's Last Wilderness*. David Attenborough and Colin Butfield. 2025. John Murray Press, Hodder & Stoughton Ltd., London, UK. 384 pp. (PB). ISBN 978-1-399-81851-3.**

I picked this book to review because I suspected it would be enjoyable and therapeutic. Enjoyable? Yes! Who isn't familiar with Attenborough's wonderful voice narrating scenes of some of the most extraordinary natural environments on earth. He has truly been a champion of biodiversity and has brought many couch-bound screen watchers to the realization that nature is wonderful and that we should reduce our impacts on other living beings. It is therapeutic! His strong message about environmental protection is needed more than ever when our collective attention has been hijacked by the unhinged politics and wars pushed by strongmen. The book did not disappoint.

In the introduction, Attenborough and his co-author Colin Butfleid state that they wanted "to convey the thrill of discovery, be clear-sighted about the danger our ocean is in and, above all, share the stories we felt could inspire a new generation to look beyond the shore and beneath the waves". Beyond living up to these aims, the book provides many illustrations of how quickly biodiversity in the ocean can recover, if we let it.

The book is separated into sections, each describing different portions of the oceans, from coral keys to mangrove forests, to deep sea vents, to the thawing arctic, to the powerful southern ocean, to life under the ice. In each, personal observations and overall commentary combine to give a strong feeling as to the particularities, strengths and fragilities of these habitats. Having worked with marine biologists for most of my life (full disclosure - I'm an environmental physiologist and worked with a wide range of animals, mainly aquatic), the descriptions of habitats and ecosystems were quite familiar. In the chapter about the depths of the ocean, I enjoyed reliving the astonishment felt as I learned of the remarkable ecosystems at hydrothermal vents and the biochemistry that underpins them. While it contains some beautiful photographs, this is not a coffee table book with photos that live up to the visual quality to which viewers of our Living Planet are accustomed. This is a book to be read and considered.

The most "therapeutic" aspects of the book are the striking examples of how protected areas or other conservation measures have been effective in rescuing habitats from degradation caused by human

activities. During World War II, heavy mining in some areas of the ocean caused fishers to avoid the areas during subsequent years. And lo and behold, the pelagic and benthic life rebounded quickly. Another example concerns the kelp forests that once surrounded England's coast. Eliminated by dredging and drag fisheries, they are gradually being restored by combining personal memories of where the kelp once grew with restrictions on fishing practices. I learned of the vast protected areas in the ocean northwest of Hawaii and the Tallurutiup Imanga in the Arctic. Perhaps the most heart-warming example of restoration came in the painstaking efforts to recreate the mangrove forests that protected the Bay of Nicoya in Costa Rica. Given the need for mangroves to moderate tidal influence, mangroves could not simply be planted. Rather, careful satellite studies of the topography, combined with the efforts of local women who removed mud by hand, were needed to recreate the intertidal soil conditions in which mangroves can once again grow.

Being familiar with the magnificence of the ocean, the best part of this book was learning of the rapid recovery possible in many oceanic habitats. The great illustrations of the ocean's capacity to recover will be useful in discussions with folks who are reticent to change policy and promote marine protected areas. But how far will these messages go? Will readers of *Ocean* push their politicians, local decision makers and influencers to change practices? Hopefully, yes!

I highly recommend reading this book. It is an easy read with many enjoyable "ah so" moments.

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The Many Lives of James Lovelock. Science, Secrets, Spycraft and Gaia Theory. **Watts, Jonathan. 2024. Greystone Books, Vancouver/ Berkeley/London. 312 pp. (HB). ISBN 978-1-77840-248-7.**

In 2006 the Geological Society of London awarded its Wollaston Medal to James Lovelock, saying in the citation:

> Even in the illustrious history of the Society's principal medal, first awarded to William Smith in 1831, it is rare to be able to say that the recipient has opened up an entire new field of study in Earth science But such is the case with this year's winner James Lovelock…The view of the planet and the life on it as a single complex system, analogous in some ways to a homeostatically self-regulating organism, is what gave birth to the field we now know as "Earth System Sciences"…

The "self-regulating organism" in various guises espoused by Lovelock and many others was named "Gaia". It still governs much environmental thought, and, as the Wollaston citation suggests, is well imbedded in 21st century biogeochemical science linking the biosphere with the Earth's atmosphere and physical fabric.

James Lovelock (1919-2022) lived a long and intricately unfolding scientific life that has been outlined by several others (and himself). It has been summarized in a complete and well-documented entry online in Wikipedia. This is a very good starting point, but Jonathan Watts' new book is an essential complement and expansion of what has gone before, based on detailed use of the Lovelock archive, now in the Science Museum (London), Lovelock's personal correspondence, and two years of interviews with the aged Lovelock in his retirement home in coastal Dorset. The result is a compulsively readable biography, wide-ranging, sensitive and thoughtful, of a most unusual and imaginative scientist in several very human settings.

James Lovelock seems at the outset to have been an unlikely scientist, unmathematical, with a spotty school career, a variety of science-related jobs during the Second World War, an interest in chemistry, gadgeteering, and explosives, and eventually in 1948, a Ph.D. from the London School of Tropical Medicine. He spent 20 years working on a series of biomedical studies in the National Institute for Medical Research in London. But his invention of the electron-capture detector in 1957 greatly increased the sensitivity of gas chromatography and led

to his involvement in the early exploration of the Martian environment in the United States during the 1960s, and in many other studies. During the next couple of decades he took on a consulting role into subjects like the Martian atmosphere, tetraethyl lead in gasoline, the influence of petrochemical industries on the Earth's atmosphere, the atmospheric distribution of CFCs (chlorofluorocarbons), and for the UK's intelligence services, detection of explosives during the Troubles in Northern Ireland. Throughout, he lived from consultancy to consultancy, establishing personal laboratories at home in England and in a summer retreat in Northern Ireland.

Watts' approach is largely chronological, but using the interesting and original technique of relating Lovelock's life and career in separate chapters to a series of people: his parents; his first wife; children; scientific colleagues (and one opponent); British men of affairs; lovers; his second wife; then finally a thoughtful exploration of his varying approach, at life's end, to the Gaia hypothesis and environmentalism. Each is a deeply-researched essay on a scientific life that is well outside the ordinary.

A few examples. The chapter "Dian" deals with the 1960s and Lovelock's collaboration with the American scientist Dian Hitchcock to develop techniques useful in determining the presence of life on Mars. Both came to realize that on Earth oxygen, and especially methane, were the result of life, and that (as it proved) their absence on Mars and the prevalence of carbon dioxide precluded life on that planet. It was thinking about that problem together with Hitchcock that provided the spark of the Gaia hypothesis. "Victor" deals with Lovelock's relations with Lord Victor Rothschild, in charge of Royal Dutch Shell's research, who invited him in 1967 to write "a memorandum on what the world will look like in the year 2000 and what effect it will have on a company such as Shell". As Watts writes, "The correspondence between the two men, much of it confidential and unpublished until now, provides a blow-by-blow account of how a fossil fuel company came to realise it was wrecking ecosystems, degrading human health and destabilizing the climate, only to cover up the evidence, downplay the risks and blame others." Rothschild became not just a patron to Lovelock but also his entrée to the British intelligence services, which were interested in his ability using chemical tracers to find combatants and explosives. For Lovelock, one outcome of his relationship with Rothschild was to stabilize his personal finances and equip his laboratory, although

at the cost of secrecy about his work, publications and opinions. It also led Lovelock to the relationship between industrial pollutants and climate change – the climatic cooling detected in the 1960s and the countervailing warming caused by carbon dioxide emissions.

Finally (for my discussion here), there is "Lynn", a chapter outlining Lovelock's friendship and scientific relationship with the prominent American biologist Lynn Margulis, who as a master investigator of the evolution of endosymbiotic microbial life, brought new ideas to his developing Gaia hypothesis. It was she who joined Lovelock in the first scientific exposition of Gaia, "Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis" in the Swedish journal *Tellus* in 1974. This was also the time that Lovelock had to come to grips with the fact that his own measurements showed that CFCs were widespread globally, and that they showed evidence of breakdown at high altitudes, releasing halogens that resulted in what came to be known as the ozone hole. This contradicted his earlier belief and pronouncements that CFCs were environmentally neutral and were not a threat to the Earth system at the heart of Gaia. Through the ups and downs of promoting Gaia, Lovelock was under fire as an apologist for the chemical industries, travails that he shared in correspondence with Margulis who acted as a concerned counterweight to her increasingly stressed colleague. She was a trenchant critic too, When Lovelock's book *Gaia: A New Look at Life on Earth* was published in 1979, she claimed that the Earth was not an enormous organism as Lovelock then claimed but an equally large ecosystem. Throughout, she remained one of Lovelock's fiercest critics and also one of his most cherished friends.

Watts' remarkable book about James Lovelock evokes a time (mainly the 1960s and '70s) when "Earth Systems Science" emerged from environmental sciences that were becoming increasingly precise and increasingly global, while at the same time the biosphere began to look increasingly fragile. During that era, when I began graduate studies at Yale under G. Evelyn Hutchinson, Hutchinson's "biogeochemistry" could, with time, merge almost insensibly into a Lovelockian organismic approach to the biosphere and its physical framework, that is, into accepting some kind of Gaian superorganism. To some of us it did, to others not so. Watt shows how even Lovelock wound a twisting path through the use of the environmental measurements he exceled at, gaining scientific triumphs but also subject to human uncertainties scientific, political and personal. These often governed how he thought

about his science, how it should be pursued, and how it should be promoted. It is rare and very thought-provoking to read a scientific biography that is so revealing of science as a human pursuit.

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George, R. (2025). *Every last fish. A deep dive into everything they do for us and we do to them*. New York: W. W. Norton & Company. [xii], 292 p. ISBN 978-0-393-88147-9.

Fishing activities have characterized coastal areas in Atlantic Canada for centuries. First Nations communities harvested fish for food and other purposes for millennia before Europeans ventured across the Atlantic beginning in the early 1500s to collect fish for European consumption. Over the past 500 years fisheries have been a major economic factor in this region (Lear, 1998). Today, for example, the Nova Scotia seafood industry, valued at >$2.2B, continues to be a significant contributor to the provincial economy (MacDonald, 2026; Nova Scotia Department of Fisheries and Aquaculture, 2026). Although never limitless, fish stocks have often been treated as if they were inexhaustible. The devastating impact of the 1992 moratorium on the cod fishery, particularly for communities in Newfoundland and Labrador (Eddy, 2026), dramatically illustrated misunderstanding of the capacity of marine ecosystems. Significant marine biodiversity loss is now widely reported. The *2026 State of World Fisheries and Aquaculture* notes that marine fishery stocks fished within sustainable levels continue to decline and the report frankly states that achieving the "SDG target of 100 percent of stocks within biologically sustainable levels remains extremely challenging" (Food and Agriculture Organization of the United Nations, 2026, p. xv). Pillaging of the ocean seems to describe humanity's ongoing relationship with marine life, which with today's technologies could mean exploiting all marine species.

In an aptly titled book *Every last fish,* Rose George offers readers an engaging and informative window into many perspectives of fish life, the fishing industry, and our shared future with marine ecosystems. A journalist and acclaimed author, George immersed herself in fishing activities to meet with real people around the world – divers, biologists, fishers of various types including women and men whose livelihood depend on marine species – and write about the challenges, risks, and dangers of working in aquatic food systems that today employ more than 65 million. The result is a captivating book on a subject that matters to everyone concerned about food security and the health and sustainability of the planet.

Organized in 15 chapters, the book begins with George's own experience in diving in the Bay of Dakar off the coast of Senegal and finding the "sea is alive." Not nearly so full of life as previously, as Daniel Pauly, prominent University of British Columbia fisheries researcher, tells her. Pauly starkly states that the "idea that we can still fish sustainably is nonsense," (p. 6) because the shifting baseline of marine life is continually trending downward. The opening chapter establishes the status of global fisheries from which George takes readers onto a boat with a fisher in UK waters in the second and then around the world in the following chapters. Each chapter is an essay that reveals the diverse experiences of people who work in the seafood industry or who study marine life: workers in the fast fish food business and a school for training fish frying; an investigation of the tragic loss of life in a fishing accident in waters off Alaska; the difficult, demanding practices that women encounter in the industry; the perspectives of trawl fishers; the experiences of small-scale fishers turned into a small-scale navy in World War II; the lonely, life-threatening careers of fish wardens and fisheries officers; the risks and slave-like work of fishing crews; observations about the controversies and operation of salmon aquaculture in several countries, e.g., Norway and Scotland; implementation of off-shore renewable energy use, primarily wind energy, and the impact on fish and fisheries; and the effects of ghost fish gear, and the implications of conservation measures and international treaties, e.g., the High Seas Treaty also known as the BBNJ Agreement.

By reaching into the lives and experiences of people working in the seafood industry and calling attention to the treatment of marine species worldwide, George presents an empathetic and informative account of a major global activity. It is easy to be gripped by her storytelling approach and writing style and become very concerned about the state of fisheries and deteriorating ocean ecosystems. George concludes the book on a positive note, though. "We are not helpless," she states. "Better data will help: It will help us understand what fishing boats are actually up to; it will help us understand more precisely how fish are doing; it will help everything" (p. 242). To aid readers in making decisions about which fish to consume, she included a helpful guide of resources to check. The book is well-documented with many citations and a select bibliography that includes studies by noted Canadian researchers, e.g., Daniel Pauly (University of British Columbia) and Boris Worm (Dalhousie University). Minor errors (e.g., reference

to Labrador as a "Canadian province" p. 46) and the poorly printed photographs notwithstanding, this book is recommended to all members of the Nova Scotian Institute of Science and to readers everywhere who are interested in marine ecosystems and environments.

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Proceedings of the Nova Scotian Institute of Science (2026)
Volume 54, Part 2, pp. 635-647

NSIS FIELD EXCURSIONS 2025-2026

LEGACY GOLD MINING IN NOVA SCOTIA

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On September 20, 2025, fifteen NSIS members and guests participated in an excursion to Waverly to learn about Legacy Gold Mining in Nova Scotia. Historically, gold mining in NS took place in three main phases between 1860 and 1942. A total of about 1.2 million ounces of gold were recovered, which was substantial. (For comparison, the Yukon yielded about 20 million ounces.)

We learned that Waverley was one of the more productive of about 60 provincial gold-producing areas, with (mainly) underground mines over a wide area, and extensive infrastructure for extracting the gold from the ore. The ore was crushed in stamping mills and the powder or dust passed as a slurry over mercury-covered plates. The resulting Au-Hg amalgam was then heated to drive off the mercury and leave the gold.

The process leaves large amounts of waste – at Waverley this came to about 3 million tons of waste rock or tailings that were deposited in an unregulated manner all over the region, including into bodies of water and wetlands. These tailings also included significant amounts of mercury from the refining process, as well as arsenic which often occurs naturally in gold-bearing rock. In addition, cyanide was sometime used for gold extraction in the later years, so that is found in some of the tailings, too.

We met at the Waverley Heritage Museum (Fig 1, Fig 2), which has a very nice collection of historical artifacts and exhibits, some devoted to the gold-mining era. Our hostess was Pat Clahane, a volunteer at the Museum. She was joined by Bradley Knockwood, a student in Dr. Linda Campbell's group at SMU which is working on remediation issues at these sites.

Bradley started by showing us a newly-created map app which can show many aspects related to Waverley gold mining (Fig 3). The user

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Fig 1 Waverley Heritage Museum.



Fig 2 Inside the museum.

can call up layers that show the locations of all the gold seams and mines, the buildings, previous maps, the areas of tailings, the hydrology and topology, and much, much more. This was useful in getting us oriented to the location and extent of the activities, in contrast with the tranquil village today.



Fig 3 Bradley lecturing.

Then Pat took us into the museum and presented a description of the historical evolution of the mining in Waverley through the three main periods of activity, and well as the social aspects of the periods (Fig 4). She also used some of the exhibits to effectively illustrate the mining and extraction operations (Fig 5).

After a brief break for coffee and snacks, we walked over to Village Green, a public park next to the Shubenacadie Canal. Bradley explained that the park is distinguished by being right on top of a large deposit of mine tailings. (Being so capped the tailings are not a present-day threat.) This position (Fig 6) affords a view of the steep hillside where a very large stamping mill did its work. Remnants of its foundation are still visible. It was powered by electricity generated by a flow of water which came several miles by pipeline from Miller Lake and dropped down to a turbine next to the canal. The foundations of the turbine and exit pipe are still in place at the edge of the park.

We walked back to our cars at the museum and drove to nearby Muddy Pond (Fig 7), which was infilled with tailings to the point where it is now more of a swamp than a pond or lake. Unlike the Village



Fig 4 Pat demonstrating.



Fig 5 Model of the process.

Green, this area is quite contaminated, and access is by permit only. Bradley described aspects of the extensive and multi-year research being conducted in the vicinity. It touches on hydrology, levels of contamination, effects on flora and fauna, and much more.

With respect to present-day mining operations, it seems that things are much better. There are strict regulations and requirements to minimize environmental impact, and the companies seem to be striving to comply. Much has been learned from the mistakes of the past. The processes are cleaner and better controlled, the tailings are cleaned of substances such as arsenic and cyanide, and the tailings are confined under water in sealed impoundments or open pits.

It was a very interesting and educational day, enhanced by lovely weather. Pat and Bradley, our host and guide were excellent, full of enthusiasm, and very good instructors. And Bradley's indigenous roots added a Mi'kmaq perspective to some of the environmental issues involved. Everyone learned a lot on this excursion.



Fig 6 Looking up to the Processing Site.



Fig 7 Viewing the site at Muddy Pond.

BLUE BEACH AND AVON RIVER EXCURSION, NOVA SCOTIA

On 6 June 2026, sixteen NSIS members and guests participated in an excursion to two sites on the Avon River in Kings and Hants Counties. The first site was at Blue Beach, between Hantsport and Avonport, and the second site was along the Pisiquid Lake portion of the Avon River in Windsor.

We spent the morning first at the Blue Beach Fossil Museum[1] and then on the Beach itself. Blue Beach (Fig 1) is a world-class and world-famous fossil site and has long been known by paleontologists and geologists for its unique treasures – especially the first evidence (in 1841) for the presence of vertebrates in the Carboniferous. It is now important for evidence of the invasion of the land by the first vertebrates to leave the sea, the so-called "Romer's Gap"[2,3]. The fossil trackways make Blue Beach the official birthplace of vertebrate paleontology in Canada.

We met our host and guide, Chris Mansky (Fig 2), at the Blue Beach Fossil Museum. He has dedicated over two decades collecting and



Fig 1 Blue Beach on the Avon River.

[1] www.cbc.ca/news/canada/nova-scotia/blue-beach-fossil-museum-chris-mansky-funding-1.5237511

[2] Blue Beach Fossil Museum. (2026). History & Geology, Age and Geological Setting, Milestones in Previous Research, Romer's Gap, The Fossils, Tetrapods, Fishes, Invertebrates, Plants. www.bluebeachfossilmuseum.com/

[3] Anderson, J.S., *et al.* (2015). A diverse tetrapod fauna at the base of 'Romer's Gap'. PLoS One. 2015. Apr 27;10(4):e0125446. doi:10.1371/journal.pone.0125446



Fig 2 Explaining fossils.



Fig 3 Chris Mansky

cataloging over 10,000 specimens from the beach resulting in an extraordinary paleontological record going back 350 million years. Chris used samples from the collection to teach us a lot about ..the geologic period, fossil-forming processes, things that may be seen in samples from the beach, and much more (Fig 3). For example, we learned that the term "fossil" only applies to items derived from living things such as "body fossils" – bones, shells, leaves, branches. "Trace fossils" are impressions left by living things – footprints, worm tunnels, etc. Other common features are from non-living processes – sedimentary features of wave action, mud cracking, etc.

We also learned that specimens exposed by splitting apart two sedimentary layers often appear in both pieces, one as a convex (raised) feature and the other as a concave (depressed) feature. So, depending on which rock is found, a footprint may be concave (as you'd expect) or it could be a raised impression.

Chris also explained the significance of the finds at Blue Beach – those that provided the earliest evidence of evolving creatures moving from aquatic existence to a terrestrial way of life. These four-footed tetrapods were abundant and the museum has many trace fossils of their footprints[4].

[4] Mossman, D.J. & Grantham, R.G. (2008). *Eochelysipus horni*, a new vertebrate trace fossil from the Tournaisian Horton Bluff Formation, Nova Scotia. Atlantic Geoscience 44: 69-77. doi.org/10.4138/5933



Fig 4 On the beach.

After a wide-ranging discussion and Q&A, we moved down to the beach[5] which, as planned, was at low tide (Fig 4). It was littered with sandstones, siltstones and shales that had been eroded out of the cliffs and moved up and down along the coast by Bay-of-Fundy tidal action. The period of formation was 350 million years ago, long before dinosaurs, so we weren't going to see anything large. But based on what we had learned in the museum we realized that something of interest could be seen in nearly every apparently-plain-looking rock. Usually these were simple examples, but once in a while something like mud-worm traces or even a tiny piece of fossilized bone could be seen, and occasionally nice-looking footprints. We all had an enjoyable and interesting time looking at rocks and bringing them to Chris to identify what we had found (Fig 5, Fig 6).

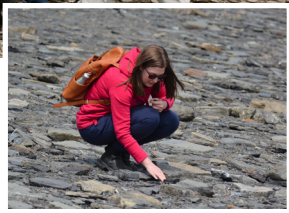


Fig 5 Fossil hunting.



Fig 6 Footprint (upper right).



Fig 7 Along the trail.

[5] Werle, D. (2026). Regional and local setting of the Blue Beach fossil cliff area in Nova Scotia, as seen by Earth observation satellites. Maps and text. Werle (personal communication).



Fig 8 A fossil seashell.



Fig 9 A nice gypsum sample.

After our visit to Blue Beach, most of us had a very nice lunch at an establishment in Windsor and then moved on to re-group at the Clifton Museum Park (formerly known as Haliburton House Museum). Tim Fedak then took us on a guided geological walk along part of the lovely Riverview Trail next to the Avon River (Fig 7). The river was once an extension of the large Windsor Sea that covered all but the mountainous highlands in Nova Scotia from about 335 million years ago[6].

There was a high escarpment along the walk, and in parts it was limestone and in other places gypsum. These materials are different from those we saw at Blue Beach and were formed in a slightly later period. Tim took us to a limestone section that provided many pieces of easily-splitable rock, and we were able to find some fossils, mainly of small seashells (Fig 8). Further along the trail Tim showed us sections of pure gypsum (Fig 9), and he explained how gypsum is transformed into plaster. Today gypsum is the basis of drywall construction panels, making it an important Nova Scotian export. As we made our way back to Clifton Museum Park, Tim pointed out several large limestone sinkholes on the perimeter. He noted that all of the numerous fossil mastodons found in Nova Scotia were victims of falling into similar sinkholes, and it has been shown that they did so in different interglacial periods.

[6] Fedak, T. (2026). Map of Nova Scotia showing the various geological groups of the Carboniferous period, plus a map of the Windsor Sub-basin, and relevant references. Fedak, (personal communication).



Fig 10 The End of a Good Day.

It was a very full and educational day (Fig 10), and we learned much that was new to us about the geology and paleontology of this region of Nova Scotia. Most of us pay scant attention to the geological features all around us, and this day taught us that there is much to be learned, even from seemingly insignificant surroundings. As a bonus, the weather was good and the landscapes were scenic. We all felt that it was a very successful excursion.

Acknowledgements Thanks to Tim Fedak for his comments and suggestions about the text, and to Peter Wells who provided the references. And thanks to Tim Fedak and H. Wayne Garland, who provided some of the photographs.

EXPLORING KEJIMKUJIK NATIONAL PARK AND NATIONAL HISTORIC SITE

PETER G. WELLS*

Dalhousie University, Halifax, NS

Once again (Bird 2023), the NSIS sponsored a Saturday summer trip to the fabulous Kejimkujik National Park and National Historic Site, with the primary aim to have a guided tour of the indigenous petroglyph site on the edge of Kejimkujik Lake. The trip went really well, with 7 of us at participating at the start, then 5 of us after the petroglyph tour. I checked at the park on Friday afternoon to confirm the guided tour. They were all set for the tour but unfortunately could not provide a naturalist for a guided interpretive forest walk as in previous years (Bird 2023). Undeterred, some modest afternoon hikes were proposed instead.

On the Saturday morning, after meeting at the Visitors Center, we drove to parking lot one at Merrymakedge Beach. Two very knowledgeable parks staff met us and explained the history of the Mi'kmaq cultural landscape at Kejimkujik, while standing in front of the beautiful historic site monument (Fig 1). We then walked a forest trail over to the petroglyphs, located on large rocks at the lakes edge. We walked on the rocks in bare feet (no boots allowed) and saw the various engraved carvings up close (Fig 2, 3). They are hard to see, worn down by age and lake ice, but the guide pointed some out to us and explained their cultural significance. Fortunately, this site is now protected against vandalism.

After the informative morning tour, we lunched at Merrymakedge Beach, enjoying the beautiful view across the lake and canoeists in the distance. Surprisingly, there were few other people, but the café was open for coffee and snacks. After lunch, I guided five of us on two walks – Peter Point, seen stretching into the lake across from the beach, and the well-trodden path from the visitors center alongside the Mersey River and its water falls. Both walks immersed us in the beauty and tranquility of the park. The weather was perfect and there were few bugs to bug us! All in all, it was a fine late summer's day. We enjoyed lots of good conversation and took lots of photos (Figs 4). Everyone arrived home safely after a long day. Please stay tuned to our excursion program as next year awaits!

* Author to whom correspondence should be addressed: oceans2@ns.sympatico.ca.

Acknowledgements We thank Parks Canada staff for their time and expertise, making this trip a success, and trip participants for their pictures.

REFERENCES

Bird, H.M.B. (2023). NSIS Excursions 2023. *Proceedings of the Nova Scotian Institute of Science* 53(1): 153-156.



Fig 1 **Park interpreters at the Historic Site Monument (Helga Guderley).**



Fig 2 **Petroglyphs on the Keji Lake shoreline (Helga Guderley).**



Fig 3 **The park interpreter Jonathan describing the significance of the various petroglyphs on the Keji Lake shoreline (Michelle Paon).**



Fig 4 **The happy hikers on the shoreline at Peter Point, Kejimkujik Lake.**

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NSIS COUNCIL REPORTS

Reports from the Annual General Meeting
June 1, 2026 - 7:30 pm

AGENDA

165th ANNUAL GENERAL MEETING

Meeting held in Sobeys Building Room 255,
Saint Mary's University, Halifax, NS, and via Zoom

1. **Welcome (**Jillian Phillips)
2. **Minutes of Previous AGM:** (Tanner George)
3. **Annual Reports:**
   President (Jillian Phillips)
   Treasurer (Angelica Silva)
   PNSIS Editor (David Richardson for Peter Wells)
   Membership (Barb Zielinski)
   Publicity (Eli LeDrew)
   Website (Ailish Sullivan)
   2025/6 Lecture Programme Recap and Upcoming 2026/7 Lecture Programme (Alana Pindar)
   Excursions (Hank Bird)
   Student Science & Technology Writing Competition for 2026 (Connor Smith)
   Motion and Vote to accept the 9 reports.
4. **Awards:**
   Recognition of new Hall of Fame Member Dr. Axel Becke (Dr. Mary Anne White)
   Writing Competition Awards (Connor Smith)
   Words from Writing Competition Participants
   Travel Awards for 2026 (Brent Robicheau)
5. **Council for 2026-2027:** (Jillian Phillips)
   Nomination of 2026-2027 Council.
   Motion and Vote to approve the new Council.
6. **Other Business:** (Jillian Phillips)
   Any Other Business?
7. **Adjournment:** (Jillan Phillips)

Council Members & Observers Present: Jillian Phillips (President), Tanner George (Secretary), Angelica Silva (Treasurer), Hank Bird (Excursions), Bruce Hatcher (Councillor), Barbara Zielinski (Membership Officer), Sean Haughian (Observer, NS Museum), Ailish Sullivan (Webmaster), Helga Guderley (Councillor), Eli LeDrew (Publicity Officer), David Richardson (Associate Editor), Peter Wells (PNSIS Editor), Brent Robicheau (Vice President), Connor Smith (SSTWC).

Regrets & Absent (Council Members & Observers): Derick Lee (Councillor), Judy MacInnis (Councillor), Stephanie MacQuarrie (Past President), Alana Pindar (Speaker Series Chair), Jinshan Xu (Councillor), Shannon Ezzat (Councillor).

Members and Guests Present: John Young, Valeria Montes, Samuel Sequeira, Dayle Sirko, Grace Ogrady, Hsiang Yu Chang, Olivia Murphy, Kelly Murphy, Adunola Oyenola, Olaitan Oyetola, Adunola Oyenola's younger sibling, Michelle Paon, John Macneil, James Anderson, Cherif Matta, Judy Bird, four whose names weren't marked down.

Online: Islam K. Mater, Tehya Mohammad, Michael Casey, Nicole Wright, Jim Elliot

1. **Welcome (Jillian Philips)**
   Jill begins with a general introduction to the crowd for the 165th NSIS AGM.

2. **Minutes of Previous AGM: (Tanner George)**
   Minutes of the 164th AGM from 5 May 2025.
   Motion and Vote to accept last years Minutes of the 164th AGM.
   Motion by Bruce Hatcher, Second David Richardson.
   10 votes in favor, none against.

3. **Annual Reports**

4. **President (Jillian Phillips)**
   NSIS 2025–2026 Highlights

   Comprised of a dedicated group of member-volunteers, the NSIS Council continues to promote science in NS and actively seeks new members and funding to support our initiatives. I sincerely thank everyone serving on this year's council for their dedication and invite others with a passion for science to join us, share the responsibilities, and contribute to advancing our mission.

During the 2025/26 year, NSIS council and editorial board continued our mission to promote science in Nova Scotia through:

Public Engagement

- Hybrid Public Lecture Series with a Diversity of speakers
- Thank you to Alana Pindar for your continued speaker reach out and organization contributing to a successful lecture series and secretary Tanner George for organizing rooms on campus at SMU and DAL
- Social posts acknowledging current science initiatives and days of scientific interest/importance

Scholarly Publishing

- PNSIS volume 54-1 is currently available, open access; new issue 54-2 is in progress
- Thank you to the ongoing work of Editor Peter Wells, Assoc. Editor David Richardson, and our editorial board

Student Opportunities

- Student Science and Tech Writing Competition (thank you to Competition Coordinator Connor Smith and all our judges)

Community Outreach And Excursions

- Financial support for school science fairs, and youth science fair judging
- Excursions with a scientific element for members and guests

Scientific Recognition

- New NSIS Hall of fame inductee for 2026

5. Treasurer (Angelica Silva)

Report available, not going through all details explicitly. Roughly 10K out, less then 10K in, mostly due to donations. Biggest expense includes PNSIS publication, and awards to students along with donations to other educational institutions.

NOVA SCOTIAN INSTITUTE OF SCIENCE **1862-2026**
2025 -2026 – NSIS AGM – FINANCIAL REPORT
April 1st, 2025-March 31st, 2026
Halifax, Nova Scotia-June 1st, 2026

ASSETS 2025-2026

BMO account as of March 31,2026	$20,665.03
BMO GIC (January 2027)	$10,000.00
TOTAL ASSETS AS OF MARCH 31, 2026	**$30,665.03**

REVENUE (April 1st, 2025-March 31st, 2026)

NSIS Membership regular	$2,370.00
NSIS Membership Life	$1,200.00
NSIS Students	$400.00
NSIS Membership Institutions	$180.00
PNSIS sales	$35.00
Income/ACCESS Copyright Royalties	$403.71
Donations:	$6,152.00
GIC Income investment interest 2025 (BMO)	$562.50
AGM dinner	$1,600.00
TOTAL REVENUE 2025-2026	**$12,903.21**

EXPENSES (April 1st, 2025-March 31st, 2026)

NSIS Proceedings PNSIS /Printing	$951.59
NSIS Proceedings PNSIS/Layout	$2,964.00
AGM Lecture costs	$2,035.00
NSIS 2025 Writing Science Competition	$2,300.00
NSIS 2025 Science Sponsorships / Student Travel Awards	$1,900.00
NS Regional Science Fairs (3)	$300.00
Postage (Dalhousie, Members)	$238.91
NSIS Excursion guide miscellaneaous	$170.00
NSIS refund to member	$40.00
NSIS website Annual fee (3 years) - due 2027)	$0.00
TOTAL EXPENSES 2025-2026	**$10,899.70**

NSIS FINANCES 2025-2026

This is the Nova Scotian Institute of Science (NSIS) 2025-2026 year-end financial status report to be presented at the NSIS 2026 AGM on May 4th, 2026. This report contains all income and expenses from April 1st, 2025 to March 31st, 2026. This NSIS report will be attached to CRA Charities submission and it will posted within the Proceedings of the Nova Scotian Institute of Science (PNSIS) 2026 edition.

NSIS 2025-2026 total assets as of March 31, 2026 are $30,665.03, which includes BMO account at $20,665.03, plus a BMO GIC $10,000 renewed on January 2026 (due January 2027).

The NSIS 2025-2026 total income was $12,903.21 (p. 1) that included $4,150 received from all Membership Categories: Regular Members $2,370, Students $400, Life Members $1,200 and Institutional Members $180. Other income of $6,152 was obtained from: PNSIS sales $35; ACCESS Copyright Royalties $403.71; and mostly from DONATIONS $6,152 received from: University of Cape Breton $200; Genome Atlantic $500; Gud-erley $5,000; Daborn, Melville and Rawlings – each $100, Bird $2; BMO GIC interest $562.50, and 2025 NSIS AGM Dinner registrations $1,600.

NSIS Total Expenses for 2025 – 2026 were $10,899.70, (p. 2) and these resulted from costs of publishing the NSIS Scientific Journal "Proceedings of the Nova Scotian Institute of Science (PNSIS)" of $3,915.59, derived from printing costs at RAPIDO BOOKS $951.59 and Editing/Layout services by G. LeBlanc for $2,964.

The 2025-2026 NSIS Scientific Writing Competition awarded a total of $2,300 to student winners on the following categories: Graduate $800 J. Pedersen, Undergraduate $600 J Ryuzala, Hon. Mention Undergraduate $300 A. Jalal, Highschool Winner $300 S. Rimbert, and three High School Honorable Mentions of $150 each to F. Jefferies, A. Rashid and A. Kamp, later yet to clear.

The 2025-2026 NSIS Graduate Student Travel Awards for a total of $1,200 were awarded based on student applications for funding towards travel to scientific conferences to presented their work. There were 2 winners that received $500 each: A. Sergio and K. Tang and three other awards of $100 were given to J. Campbell, S. Hawkins and A. Noussis, later yet to cleared.

NSIS contributed $300 to Regional Science Fairs and did send $100 each to: Halifax Science and Technology Expo (HSTE), South Shore Regional Science Fair (SSRCF) and Annapolis Valley Regional Science Fair (AVRSF). NSIS did also contribute a total of $700 to two upcoming Science organizations, Terranaut $200 and Impoteh's Legacy Academy $500 to support Science accessibility to all. Other NSIS expenses were $40 as a refund to a member, $170 for excursions related miscellaneous and Postage for $238.91 paid to Dalhousie University.

The Nova Scotian Institute of Science had a total of 176 active members for the period 2025-2026, from the following categories: 57 regular members, 65 student members, 12 complimentary (Lecturers), 5 Honorary members and 37 LIFE Members and 6 Institutional members.

The Nova Scotian Institute of Science is a not-for-profit and Charitable membership organization that continues to dedicate all of its resources towards communication and support of scientific relevance to all Nova Scotians by publishing a Scientific Journal PNSIS, organizes an Annual NSIS Lecture series (October to May), free and now accessible live via zoom. NSIS continues its support to NSIS Student science writing competitions, NSIS Travel Awards, Nova Scotia Regional Science Fairs and other Science Events/organizations that reach out to young people.

Many thanks to Carol Richardson from Dalhousie University for continuing support and to Hank Bird for his multiple roles contributing to finance, membership updates.

Respectfully submitted
Angelica Silva, NSIS Treasurer Volunteer

6. PNSIS Editor (David Richardson for Peter Wells)

The PNSIS, Vol. 54, Part 1, 2025, was completed in Fall, 2025, and distributed to members, as well as being placed on the NSIS website.

Preparation of PNSIS, Vol. 54, Part 2, 2026, is moving ahead smoothly, thanks to the work of the Associate Editor and members of the Editorial Board. Reviews of incoming submissions are coordinated by the Associate Editor. Our monthly meeting helps to keep track of progress for the new issue, find reviewers, and encourage submissions.

To date, for PNSIS 54-2, we have accepted one commentary (two more promised), two papers (four more in review), two student papers (more expected from the 2026 student writing competition), two book reviews (two more promised), and one excursion report (one more expected). The deadline for all submissions is June 30th. We will be working hard during the summer months to complete the new Issue in time for the first NSIS Fall meeting.

We are also addressing several outstanding items of importance – the inclusion of the DOI for each contribution; possibly adding a PFL (Publication Facts Label) to the journal; publication of a large MS on lakes and climate change that has been sent to us; introducing page charges again to cover increasing costs; and continuing to strengthen the editorial board and having a succession plan for the Editors, i.e. recruitment.

Finally, we once again thank the authors, reviewers, and especially our Layout and Production Editor, Gail LeBlanc, for contributions and continued hard work on behalf of the NSIS and PNSIS.

Respectfully submitted
Peter G. Wells, Editor
David H.S. Richardson, Assoc. Editor

7. Membership (Barb Zielinski)

Jill on behalf of Barb as she had to step out. Detail provided regarding our vision to spearhead the emphasis on reciprocal donation options for institutions centered around sharing membership and our other initiatives.

Overall membership as of Apr. 30.

Category	Number AGM 2026	Number AGM 2025
Honorary	5	5
Life	37	35
Regular	60	64
Stud	65	65
Free	12	20
Total Active =	179	189

Current NSIS membership categories

- Individual Membership – honorary, life, regular, student
- Institutional Membership is $40/yr (9 institutional members in 2025)

NSIS Membership workgroup: Hank Bird, Tanner George, Bruce Hatcher, Derrick Lee, Jinshan Xu, Barb Zielinski. Follow up on report presented by Jinshan Xu at the 2025 annual meeting.

The opening of an NSIS donor/sponsor category

Goals:

- Redefine the Institutional Membership category
- Introduce - Donor (Sponsor) category (not necessarily a membership) to include secondary schools, university departments or faculties, scientific associations and nongovernmental organizations, government laboratories and agencies, corporations and companies selling science-based products and services, entrepreneurs developing science-based innovations, science related clubs and community groups.

We propose that the NSIS shift focus from actively seeking Institutional Members to seeking organizations as Donors/Sponsors to whom we offer an institutional membership as part of their benefits. We could also include an offer of free student or regular memberships for students/scientists/employees, the number depending on the size of the donation. Say, 1 to 5 for donations from $100 to $1,000+.) Provide a template spreadsheet with the membership application, to communicate the desired benefits, such as individuals within an organization.

Possible scenario

Ask institutions, companies if they would contribute a donation on the grounds of supporting the NSIS, and as a give back, we will donate individual memberships (amount per $ to be determined) that last one year. Institutions and contributing donors may also have their information listed as an advertisement/thank you for contributing to the NSIS on the website and other things they choose to support, as their donation can be tailored to our various efforts.

What the Committee Needs from the Council at this time:
Agreement that the Committee will also present how Sponsors (Institutes) will be signed up, their contributions accepted, and what new and changed webpages are recommended. Agreement that this should be coordinated with the Strategic Planning Committee.

The Benefits of Being an NSIS Sponsor

NSIS is the Original Scientific Institution in Nova Scotia with a 164-year history

- All can recognize the importance, depth, and breadth of the scientific capacity of our province.

Maintain the Archives and History of Scientific endeavour in the province

- The NSIS roots can be used as a resource for understanding the history of science within our province.

Maintain NS Science Hall of Fame, highlighting contributions of past NS scientists

- We are intent on recognizing, capturing, and maintaining a list of scientists in Nova Scotia who have made significant contributions to their field. Members submit names to be considered for distinction.

Award Honorary Memberships to active NS scientists

- We are intent on recognizing, capturing and maintaining a list of scientists in Nova Scotia who have, and continue to make significant contributions to their field.
- All members can submit names for scientists to be considered for this distinction.

Maintain an Active Membership of Practicing Scientists & Students

This list is for those in our community who wish to pay membership fees ($10-40) to be a part of our membership mailing list. Members may attend meetings and participate to the extent they wish within the mission of the NSIS.

Publish a peer-reviewed journal focused on science relevant to the province

We host the Proceedings of the Nova Scotian Institute of Science, a peer-reviewed, general science journal dedicated to research work conducted here and in the other Maritime provinces.

Present Public Lectures by high-profile N.S. scientists

Notification of each lecture, as well as the opportunity to submit requests for speakers.

Maintain the NSIS Website

- Our website features a number of resources, and opportunities for sponsorship/advertising.

Maintain Social Media Presence [LinkedIn, Twitter, ce-Book, Instagram,]

- Includes all relevant information on our activities such as public lectures, and we also are intent on sharing more information such as councillor bio's, interviews, and shared science news.

Conduct Science-centered Excursions to Nova Scotian ecosystems

- These activities include guided/organized outings to a number of locations around the province.

Conduct Student Science & Technology Writing Contest

- Ability to participate, sponsor, support, judge, or engage with un and coming scientists. Recognition of sponsors will be done for those who allow us to award students for their work.

Support & Judge Youth Science Fairs

- We provide financial support for science fairs and students, while also mediating sponsors to support Nova Scotian science fairs broadly.

Provide student Travel Awards and Support for local Conferences & Associations

- We provide opportunities for students and sponsors to support them as well, featuring advertising.

Complimentary 1-year NSIS Membership(s)*

- For sponsors wishing to support NSIS, we will offer free memberships for the donor institution that wish to participate in the NSIS, distributed based on the sponsors needs/interested people.

Attendance at our Annual General Meeting, Seminar (or Symposium) & Dinner

- This is a great opportunity for scientists in training all the way to retired experts from across the province to come together and celebrate the Science and our pursuits within the NSIS in advancing community.

8. Publicity (Eli LeDrew)

Eli details all of the social media impacts across all platforms. Helga asks about BlueSky, and suggests lower usage of the platform may be why there is less engagement.

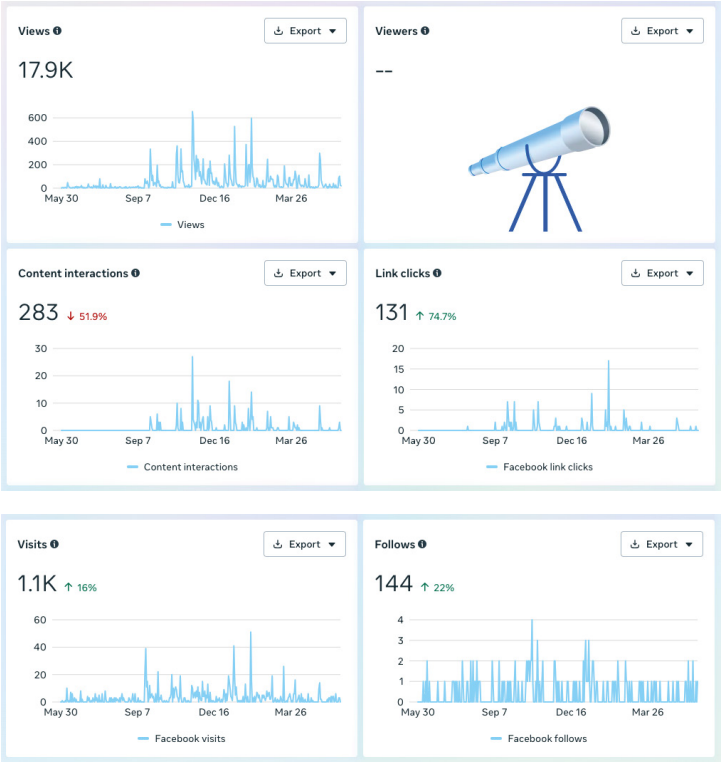
Created annual promotional material for lecture series including monthly printable posters, monthly social media banners, and annual NSIS brochure

1. Created monthly Facebook events for each lecture, advertised monthly about lecture series on Facebook, Instagram, Bluesky, and LinkedIn, as well as posted informational posts on writing competition and other relevant events
2. Emailed NSIS members, science administrators, and media outlets about upcoming lectures each month
3. Setup new BlueSky and LinkedIn accounts for NSIS
4. Assisted with judging writing competition
5. Working on creating member spotlights and other NSIS advertisements about membership and journal
   - These posts will continue to roll out into the summer months to keep engagement

Social Media Updates:

FACEBOOK (Past year 2025-2026)

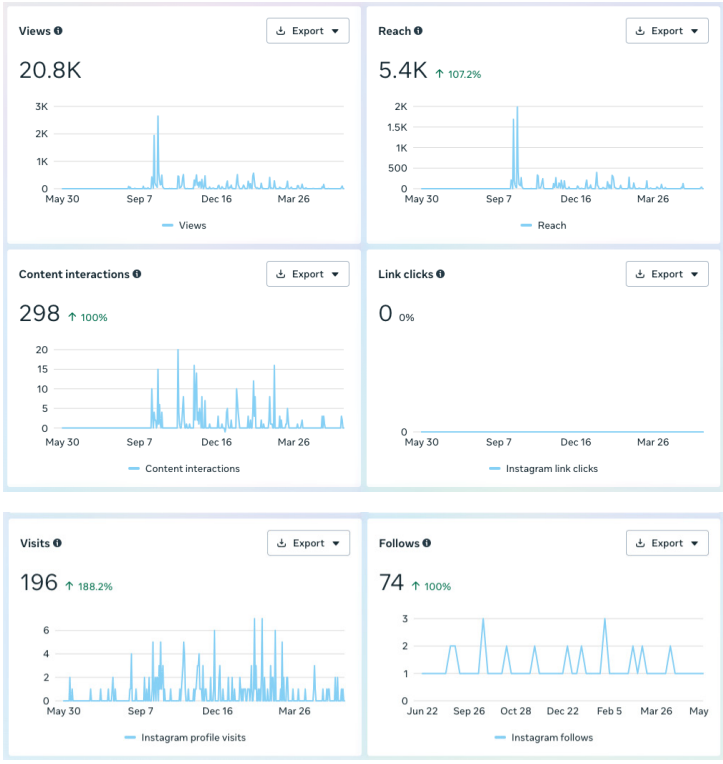




Assessment: This year (2025/2026) by the AGM we had a net gain of 129 followers on Facebook. In the 2023/2024 year by the AGM, we had gained 58 followers and in the 2024/2025 year we gained 99.

We are down 51.9% in content interactions from the 2024/2025 year but are up in Link clicks (74.7%), page visits (16%), and follows (22%).

INSTAGRAM (Past year 2025-2026)



Assessment: This year (2025/2026) by the AGM we had a net gain of 74 followers on Instagram.

We are up 107.2% in reach, up 100% in content interactions, up 188.2% in profile visits, and up 100% in followers from the 2024/2025 year by the AGM.

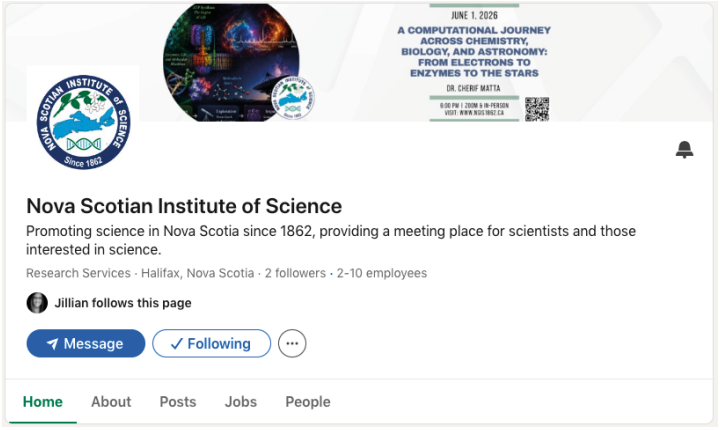
BLUESKY (October 2025-May 2026)



Assessment: Since creating the account in October, we have gained 8 followers.

Go give us a follow!

LinkedIn (March 2026 - May 2026)



Assessment: Very new account only created in March. So far, we only have 2 followers.

Go give us a follow and engage!

9. **Website (Ailish Sullivan)**
   Ailish details all of the various key updates and changes with the website, highlighting a significant streamlining done to the presentation of all content.

10. **2025/2026 Lecture Programme Recap and Upcoming 2026/2027 Lecture Programme (Alana Pindar)**
    Jill on behalf of Alana presented on the lectures, topics, future plans, and YouTube channel related to NSIS public lectures.

NSIS Speaker Series Annual Report
2025-2026 Public Lecture Series

The 2025-026 Nova Scotian Institute of Science Public Lecture Series continued to showcase the breadth and diversity of scientific research occurring across Atlantic Canada. Held monthly from October through May, the series featured speakers from several universities and research institutions and attracted both in-person and virtual audiences from across the province. Lectures were hosted at multiple locations throughout Nova Scotia, supporting NSIS's goal of making science accessible to a broad audience.

The 2025-2026 NSIS Public Lecture Series featured an exceptionally diverse collection of speakers whose research spanned ecology, evolution, entomology, climate adaptation, Indigenous knowledge systems, chemistry, sustainable materials, nanotechnology, biomedical sciences, and mathematics, highlighting the interdisciplinary nature of modern scientific inquiry and the breadth of scientific expertise across Atlantic Canada.

Reach and Engagement

The NSIS Public Lecture Series continues to attract strong engagement through both in-person and online participation. Attendance at in-person lectures remained steady throughout the year, typically drawing between 20 and 40 attendees per event. Online participation was similarly consistent, with approximately 40 individuals attending virtually for most lectures.

The NSIS YouTube channel remains one of the Society's most effective tools for extending the reach of its programming beyond the live audience. Recorded lectures from the 2025-2026 series received between 70 and 253 views, allowing presentations to remain accessible to students, researchers, educators, and members of the public long after the live events concluded. The

continued use of the YouTube archive demonstrates the value of maintaining a hybrid delivery model and highlights the importance of digital platforms in supporting NSIS's mandate of promoting scientific knowledge throughout Nova Scotia and beyond.

A significant achievement of the year was the continued geographic expansion of the seminar series, with lectures hosted outside the Halifax Regional Municipality, including events at Cape Breton University and St. Francis Xavier University. These efforts support NSIS's strategic objective of serving the entire province and increasing opportunities for participation in scientific discussions.

An additional success this year was the implementation of the "Recommend a Speaker" feature on the NSIS website. The tool has generated valuable suggestions from members and the broader scientific community, helping to identify potential speakers from a diverse range of disciplines and institutions. Several speakers confirmed for the 2026-2027 lecture series were identified through recommendations submitted using this feature, demonstrating its effectiveness as a mechanism for community engagement and program development. NSIS encourages members to continue submitting suggestions as the Society works to maintain a diverse and high-quality lecture series.

Looking Ahead: 2026–2027 Public Lecture Series

Planning for the 2026–2027 lecture series is complete, with eight confirmed speakers representing universities, museums, and research institutions across Atlantic Canada.

The upcoming series will feature:

- Dr. Paola Marignani (Dalhousie University)
- Dr. Kirk Hillier (Acadia University)
- Dr. Ryan Lukeman (St. Francis Xavier University)
- Dr. Nicoletta Faraone (Acadia University)
- Dr. Dawn Kellett (Saint Mary's University)
- Dr. Sean Haughian (Nova Scotia Museum of Natural History)
- Dr. Carlie Charron (Dalhousie University)
- Dr. Brenna Frasier (Nova Scotia Museum of Natural History)

The 2026–2027 program will continue the tradition of interdisciplinary scientific engagement, with expertise spanning plant ecology, conservation biology, biodiversity science, entomology,

pollinator ecology, marine ecology, wildlife conservation, animal behaviour, mathematical biology, natural history, and science communication. The inclusion of speakers from both academic institutions and provincial museums provides a valuable balance between fundamental research, applied conservation, and public engagement.

Acknowledgements
I would like to thank the NSIS Council, host institutions, speakers, and attendees for their continued support of the Public Lecture Series. Their contributions ensure that NSIS remains a vibrant forum for scientific discussion, knowledge exchange, and public engagement with science throughout Nova Scotia.

Best Wishes
Alana

11. Student Science & Technology Writing Competition for 2026 (Connor Smith)

Connor presented the scope of our writing contest, covering the awards, and logistics involved in organizing the competition for his first time.

SSTWC Report for the 2026 AGM

First of all, I would like to thank the judges for their help with the essays. This year, we had a successful writing competition. We received 29 submissions to the competition. Four of these submissions were for the post-secondary division, while the remaining 25 were for the high-school division. We provided three $600 prizes, one $300 prize, and two $150 prizes. The allocation of these prizes is as follows:

- 1 x $600 for the Postgraduate winner.
- 1 x $600 for the Undergraduate winner.
- 1 x $600 for the High-School winner.
- 1 x $300 for the High-School first place runner-up.
- 2 x $150 for the High-School second place runner-up, which we deemed to be a tie.

The majority of this funding came from council, while some of the prize money was graciously donated to us from outside sources.

As of writing this report, I am still working on sending out essay feedback to all of the students. I have also started a list of the students who have accepted the free one-year membership to the NSIS. I will confirm this list and send it to the council before the start of the membership period.

I hope to be able to organize this wonderful competition again next year.

Sincerely
Connor Smith, SSTWC Coordinator

12. Excursions (Hank Bird)

Hank gives a broad overview of the past excursions since Covid prevented the ability to this. Bruce is speaking on the prospects of NSIS sable island visits intended for doing active science, not just tourism. It is expensive, and challenging to get to, but they approached us to see if we (NSIS) would like to participate in active science on the island. The intent with this collaborative work would be to propose a wide range of science to actively do, and this would cost roughly 2-2.5K dollars for a round trip. The goal is to genuinely contribute to the understanding of Sable Island across all science, and all queries can be transmitted to an attending member to do collaborative work for those who cannot attend due to finances. Bruce also proposes those attending pay extra, such that an eager young poor scientist can come as well. Cherif asks if an overnight trip is possible, and Bruce clarifies it is likely a day trip only.

We did 20 excursions between 2016 and 2026, with a break from 2020-2022 due to Covid-19. We organized an excursion to Bon Portage Island in July of 2025.

We had a complement of seventeen members and guests. Bon Portage Island is currently owned by Acadia University which operates a research station there, and is also under a conservation easement with the Nova Scotia Nature Trust. It is noted for its ecological values and abundance of waterfowl. It was a perfect day, and the party explored several parts of the island. There is a description with photos of this excursion is in the latest copy of the *Proceedings of the NSIS*.

In September 2025, fifteen NSIS members and guests participated in an excursion to Waverley to learn about Legacy Gold

Mining in Nova Scotia. Historically, gold mining in NS took place in between 1860 and 1942, with a total of about 1.2 million ounces of gold being recovered. The process left large amounts of contaminated waste, about 3 million tons of tailings in the Waverley region. We started at the Waverley Heritage Museum. Pat Clahane, a volunteer at the Museum gave us a good run-down on gold mining history and processes in the area. Bradley Knockwood, a student in Dr. Linda Campbell's group at SMU (which is working on remediation issues at these sites) cartographically illustrated the legacy activities in the Waverley area, and took us to two nearby sites to see the current situation where one has been successfully capped and the other is still contaminated. There will be a description with photos of this excursion is in the next copy of the *Proceedings of the NSIS*.

In 2024 we canvassed the NSIS Membership about 10 possible excursions that we have been considering. The two excursions above were in the top 3 choices. The respondents also contributed 12 other suggestions for outings, which were added to the list, and the next three choices are being planned for 2026:

1. Geology and Fossils at Blue Beach and Clifton Museu, Park. (scheduled for June 6th)
2. Hope for Wildlife. (in progress)
3. Kejimkujik Petroglyphs and Nature Walk. (in progress)

Also, Bruce Hatcher is working with Parks Canada to see if it is possible to set up a citizen-science activity on Sable Island for a few NSIS members each year.

For the record, these are the 20 excursions we had in 2016, 2017, 2018, 2019, 2022, 2024, and 2025:

- Natural History of McNab's Island
- Annapolis Royal Historic Gardens (twice)
- The Science and Art of Making Beer (one at the Garrison Brewery, another at Two Crows Brewing Company)
- Burke-Gaffney Observatory at SMU
- 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
  - Fundy Geological Museum, Ottawa House, and the Tidal Power Exhibit.
  - Discovery Centre (including "behind the scenes")
  - Purcell's Cove Backlands (in association with Halifax Field Naturalists)
  - Halifax Citadel Drumlin Geological Walk
- Kejimkujik Petroglyphs and Nature Walk
- Scatarie Island
- Bon Portage Island
- Legacy Nova Scotia Gold Mining

Hank Bird, Excursions Coordinator

13. **Motion and Vote to accept the 9 reports.**
Motion by Hank Bird, Seconder Bruce Hatcher. 16 vote for, none against.

14. **Awards:**
Recognition of new Hall of Fame Member Dr. Axel Becke (Tanner)
Tanner Spoke on behalf of the nomination of Axel into our Hall of Fame.

Writing Competition Awards (Connor Smith)
Connor thanks our sponsors for allowing us to host this work.

Words from Writing Competition Participants
Awards were each received (most in person) and words were shared from each award winner, clearly touching the audience with their thoughtful and careful focus on choosing their topic from a personal perspective.

Travel Awards for 2026 (Brent Robicheau)
Awards include 2x 500$ and 3x 100$. Applications due July 3rd. Judges needed, let Brent know.

15. Council for 2026-2027: (Jillian Phillips)

Nomination of 2026-2027 Council

President	Tanner George
Past President	Jillian Phillips
Vice President (& Special Projects)	Brent Robicheau
Treasurer	Angelica Silva
Editor	Peter Wells
Associate Editor	David Richardson
Secretary	Tehya Mohammed
Membership Officer	Barbara Zielinski
Speaker Series Chair	Sarah Boudreau
Publicity Officer	Eli Ledrew
Web Manager	Ailish Sullivan
Library Liaison	(Vacant)

Councillors: Hank Bird (Excursions), Shannon Ezzat, Helga Guderley (SSTWC), Bruce Hatcher, Derrick Lee, Judy MacInnis, Jinshan Xu

Student Representative: Vacant (Acadia, CBU, MSVU, SMU, SSTWC)

Observers: Sean Haughian (Nova Scotia Museum), Vacant (Schools), Vacant (Discovery Centre)

16. Motion and Vote to approve the new Council.
Motion Connor, Seconded by Helga. 16 votes for, none against.

17. Other Business: (Jillian Phillips)
Any Other Business?

18. Adjournment: (Jillian Phillips)



NSIS 2026-2027 LECTURE SERIES NSIS1862.CA

October 5
Dr. Paola Marignani, Dalhousie University

From Tumour Cells to Polar Waters: Finding Biological Signals in a Changing World

November 2
Dr. Kirk Hillier, Acadia University

Restoring Balance: Management and Biocontrol of Invasive Hemlock Woolly Adelgid in Nova Scotia

December 7
Dr. Ryan Lukeman,
St. Francis Xavier University

How curiosity becomes mathematics: revealing the hidden structure in the world around us

January 11
Dr. Nicoletta Faraone, Acadia University

Raising Ticks to Stop Them: Inside Canada's Tick Research and Innovation Centre and the Fight Against Tick-Borne Disease

February 1
Dr. Dawn Kellett, Saint Mary's University

It's About Time: A History of How We Learned to Date the Earth

March 1
Dr. Sean Haughian
NS Museum of Natural History

TBD

April 12
Dr. Carlie Charron, Dalhousie University

The Trouble with Peptide Medicine, and How Chemists Are Solving It

May 3
Dr. Brenna Frasier
NS Museum of Natural History

Whale use in the Viking Age: What can we learn from medieval documents and fragments of bone?

June 7th
166th Annual General Meeting
St. Mary's University

Invited Student Speakers from Science Atlantic Conferences

Mix of talks, posters, from select recent Science Atlantic Program winners across the sciences.

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.

Online Only! @6:30pm

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

St. Francis Xavier University • Dalhousie University • Cape Breton University
Museum of Natural History • RSC/SRC • Discovery Centre

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

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Continued

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* Author to whom correspondence should be addressed: graham.daborn@acadiau.ca

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

As appropriate, **sections within the paper** should include Introduction, Methods, Results, Discussion, Conclusions, and References. Canadian spelling and SI units should be used wherever possible. References cited in the text in brackets should be separated by commas and personal communications should be as follows: Smith A.J. (2001, pers. comm.). *Scientific* names are to be in italics, as well as abbreviations such as *et al.*

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Lee, G.F. (1975). Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel, P.A. (ed.). Heavy Metals in the Aquatic Environment. Pergamon Press, Oxford, UK. p. 137-147.

Nielsen, K.J. & France, D.F. (1995). The influence of adult conspecifics and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). *Journal of Experimental Marine Biology and Ecology* 188(1): 89-98.

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projects.eao.gov.bc.ca/p/giscome-quarry-and-lime-plant/docs
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Wan, H., **Wang, X.L. & Swail, V.R.** (2010). Homogenization and trend analysis of Canadian near-surface wind speeds. *Journal of Climate* 23: 1209-1225. doi:10.1175/2009JCL13200.1

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